Aerospace Dimensions

INTRODUCTION TO FLIGHT

MODULE 1

Civil Air Patrol
Maxwell Air Force Base, Alabama

Aerospace Dimensions

INTRODUCTION TO FLIGHT

MODULE 1

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INTRODUCTION

The Aerospace Dimensions module, ***Introduction to Flight***, is the first of six modules, which combined, make up Phases I and II of Civil Air Patrol's Aerospace Education Program for cadets. Each module is meant to stand entirely on its own, so that each can be taught in any order. This enables new cadets coming into the program to study the same module, at the same time, with the other cadets. This builds a cohesiveness and cooperation among the cadets and encourages active group participation. This module is also appropriate for middle school students and can be used by teachers to supplement STEM-related subjects.

Inquiry-based **activities** were included to enhance the text and provide concept applicability. The activities were designed as group activities, but can be done individually, if desired. The activities for this module are located at the end of each chapter.

Contents

National Academic Standard Alignment

Science Standards	Mathematics Standards	English Language Arts Standards	Social Studies Standards	Technology Standards
Science as Inquiry	1. Numbers and Operations Standard: • Compute fluently and make reasonable estimates	1. Reading for Perspective	2. Time, Continuity, and Change	7. Understanding of the influence of technology on history
Physical Science: • Motions and Forces	4. Measurement Standard: • Understand measurable attributes of objects and the units, systems, and processes of measurement • Apply appropriate techniques, tools, and formulas to determine measurements	2. Understanding the Human Experience	8. Science, Technology, and Society	8. Understanding of the attributes of design
Science and Technology: • Abilities of technological design • Understanding about science and technology	6. Problem Solving Standard: • Solve problems that arise in mathematics and in other contexts	3. Evaluation Strategies		9. Understanding of engineering design
	9. Connections Standard: • Recognize and apply mathematics in contexts outside of mathematics	12. Applying Language Skills		10. Understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving
				11. Ability to apply the design process

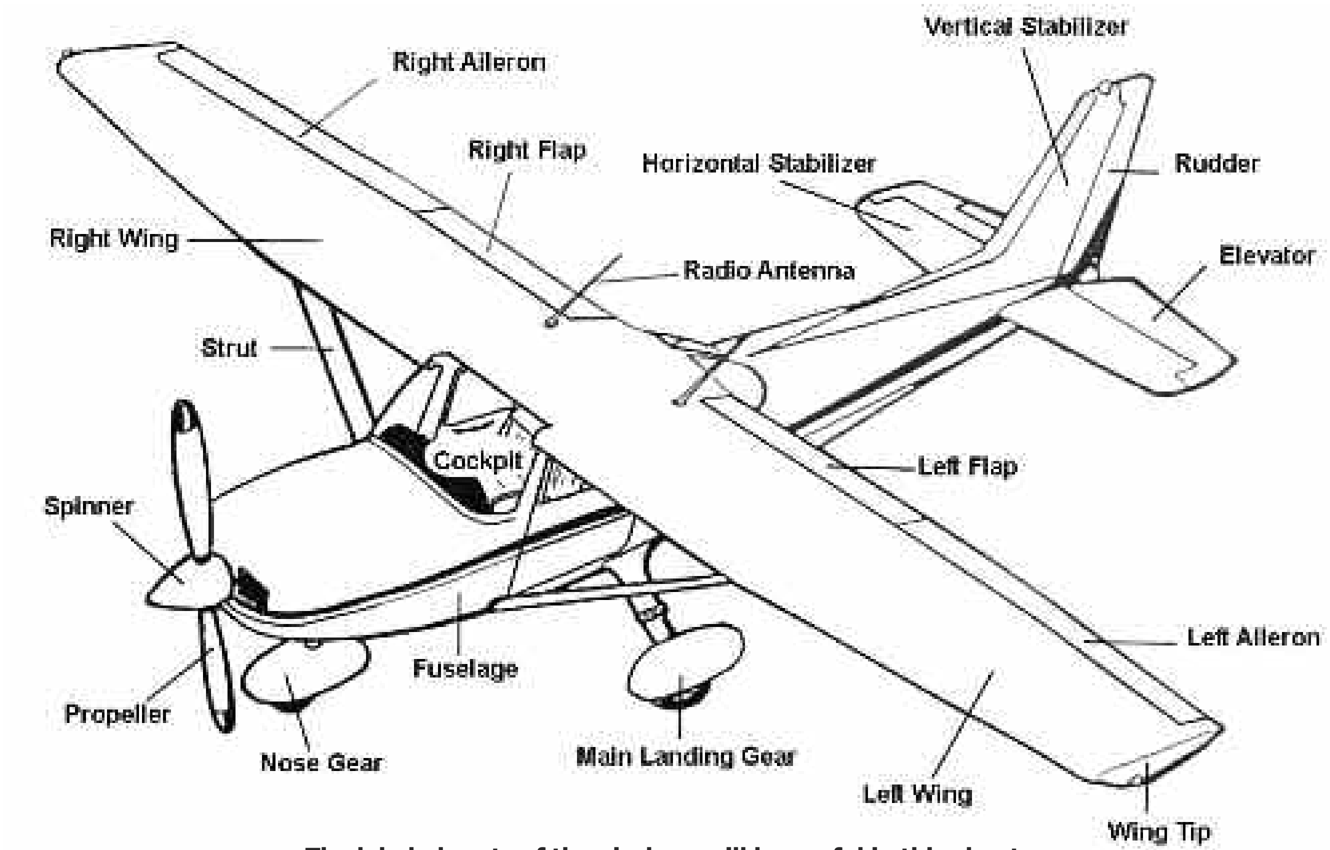
1 FLIGHT

Learning Outcomes

- Describe the relationship between Bernoulli's Principle and Newton's Laws of Motion and how they were used to develop a machine that could fly.
- Describe the coefficient of lift and the parameters involved.
- Identify the parts of an airplane and an airfoil.
- Describe the four forces affecting an airplane in flight.
- Define the three axes, movement around those axes, and the control surfaces that create the motion.

Important Terms

aero – pertaining to air
aerodynamics – relating to the forces of air in motion
aeronautics – the science of flight within the atmosphere
aerospace – a combination of aeronautics and space
air – a mixture of gases that contains approximately 78% nitrogen, 21% oxygen, and 1% other gases
aircraft – any machine that is capable of flying through the air; included are ultralights, airplanes, gliders, balloons, helicopters, hangliders, and parasails
airplane – an aircraft that is kept aloft by the aerodynamic forces upon its wings and is thrust forward by a means of propulsion
airfoil – a component, such as a wing, that is specifically designed to produce lift, thrust, or directional stability
airport – a place on either land or water where aircraft can land and take off for flight
altitude – height above sea level or ground level expressed in units
aviation – the art, science, and technology of flight within the atmosphere
aviator – a person who operates an aircraft in flight
camber – the curved part of an airfoil from its leading to trailing edge
chord – a line drawn through an airfoil from its leading to trailing edge
downwash – the downward movement of air behind a wing in flight
drag – a force which slows the forward movement of an aircraft in flight
dynamic – forces in motion
gravity – the natural force pulling everything to Earth
leading edge – the front part of a wing or airfoil
lift – the upward force that opposes gravity and supports the weight of an aircraft
relative wind – the flow of air which moves opposite the flight path of an airplane
thrust – the force which moves an aircraft forward in flight
upwash – the upward movement of air ahead of the wing in flight
vortex – a spinning column of air that is created behind the wingtip as a result of air moving from an area of high pressure on the bottom to an area of low pressure on top
wind – air in motion

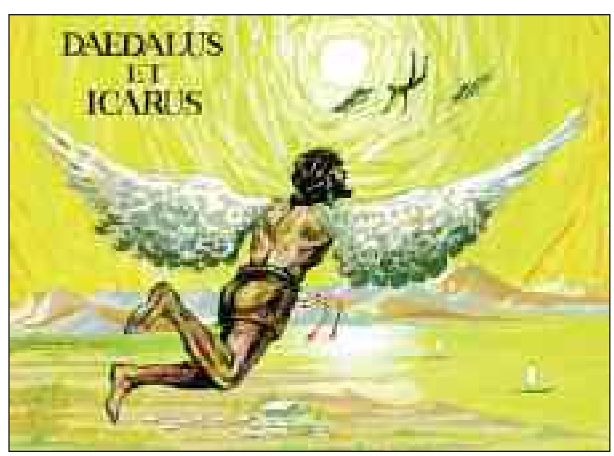


The labeled parts of the airplane will be useful in this chapter.

GODS, ANGELS, PRISONERS, AND BALLOONS

Pure mechanical flight involves using some kind of *force* to *lift* a machine upward away from the Earth, thus opposing gravity. A bird is a "living machine" that gets **lift** by flapping its wings. Once airborne, a glider is *lifted* by rising column of **air**, known as thermals. A balloon is *lifted* by a large bubble of warm air. In flight, an **airplane** is *lifted* by the dynamic energy forces of the air upon its wings. But, how did it all begin?

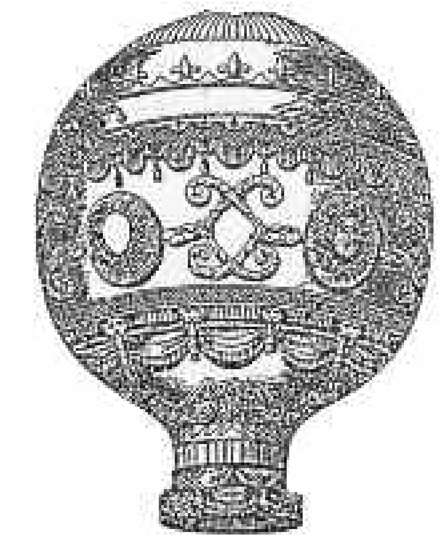
From the beginning of recorded time, there have been myths and legends about flying gods, angels, and other supernatural beings. One of the earliest recorded accounts of manned flight is an ancient Greek myth that tells of a father and son who were imprisoned on the island of Crete. They decided that the only way to escape the prison was to fly. Secretly, they collected feathers from sea birds and wax from bees to make wings for their arms. When the time came, the father, Daedalus, and his son, Icarus, quietly melted the wax onto their arms and mounted the bird feathers to make wings. When the wax was cool, they started flapping their wings and took off over the Aegean Sea in hopes of reaching freedom.



Daedalus warned his son not to fly too high or the Sun would melt the wax on his arms. Icarus was having too much fun and disregarded his father's warning, flying closer and closer to the Sun. The heat from the Sun eventually melted the wax on the wings of Icarus, and he plunged to his death in the sea.

Around 1299 A.D., it was written that the great explorer, Marco Polo, saw Chinese sailors attached to kites being used as military observers. This could be considered the first "manned aircraft."

Historians agree, however, that the first true powered flight with humans on board was in a hot air balloon and the event occurred in France during the Eighteenth Century. Brothers, Joseph and Etienne Montgolfier, created a manned hot air balloon. On November 21, 1783, pilots Pilatre d'Rozier and Francois d'Arlandes made a historic 25-minute flight over Paris . . . But, let's start from the very beginning . . .



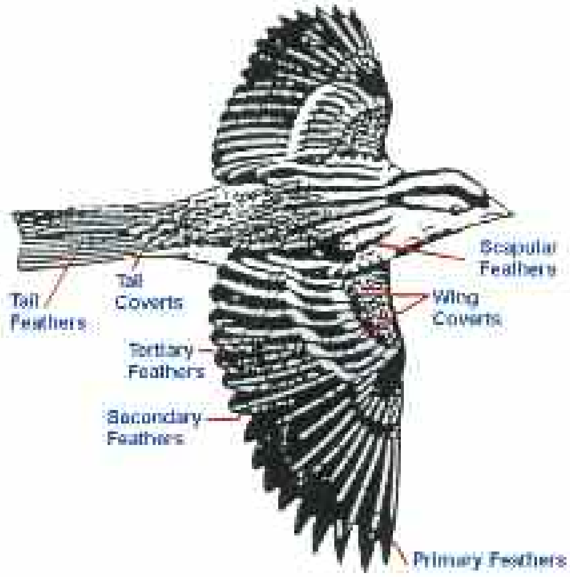
Then and Now

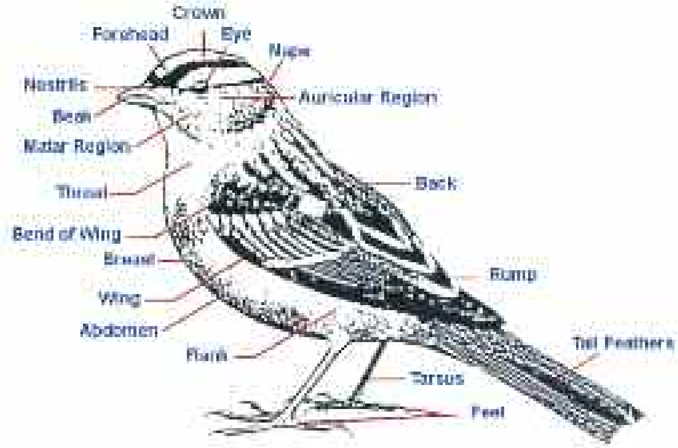
Balloons were the first known powered aircraft with humans on board.

Gliders were the first aircraft that actually had directional control. Experimental Aircraft Association (EAA)

Airplanes evolved around power and propellers. (EAA)

Jet engines provide high speed and great reliability. Although now retired, the Concorde, when in service, could carry passengers across the Atlantic Ocean at twice the speed of sound. (EAA)



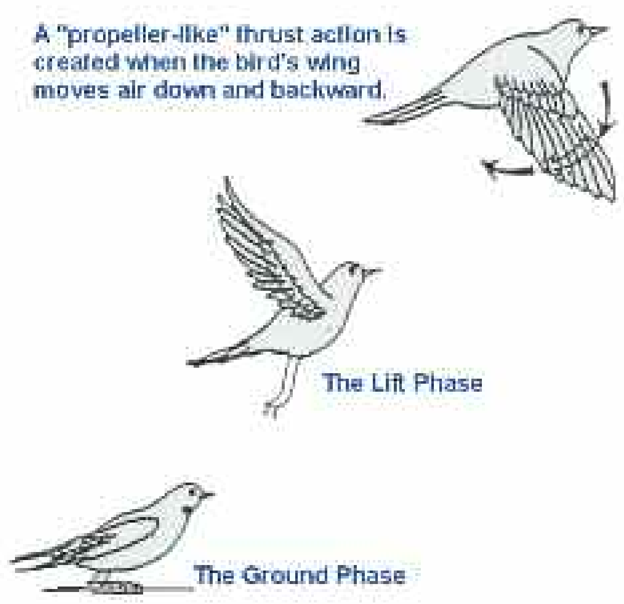


Early man studied birds, watched them fly, and even gave names to their parts ... but never quite figured out how they flew.

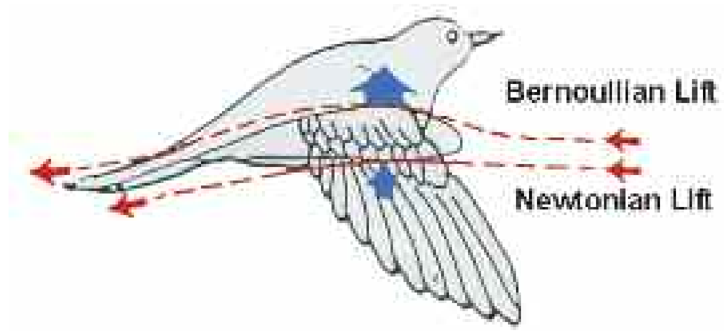
NATURE'S FLYING MACHINE

In the book ***The Fantasy and Mechanics of Flight***, the author, Paul Fortin, explains how birds fly: *"There are two phases of bird flight: a ground phase and a lift phase. The ground phase allows the bird to get started moving forward in order for the wings to provide the necessary lift. To be lifted by its wings, a bird ... must be moving forward fast enough to make air pass over its wings. A bird can move forward by flapping its wings. Most of the flapping is done by the outer wing The flight feathers work like the propeller of a plane; i.e., they push downward and backward, thereby driving the air backward and moving the bird forward. Once the bird's speed is adequate, lift over the wing is generated by the same principle as the flow of air over the wing of an airplane."*

A bird's wing is shaped somewhat like an airplane's wing. The upper surface is curved more than the under surface. Basically, the same principles of lift that apply to an airplane apply to a bird; however, the wings of a bird also act as its propeller. Once again, referring to the *Fantasy and Mechanics of Flight*, the author says, "*...Slow motion pictures of birds in flight show that the wings move downward rapidly. The wing tips trace a figure eight as they move though the air. The downward beat of the wings moves the bird forward as the outer tips push against the air. Wing feathers are arranged much like shingles on a roof. They change position when the bird is flapping. On the downbeat of the wing, the feathers are pressed together so little air can pass through them. On the up stroke the feathers open."* The down stroke of the feathers provide a strong lifting force and the opening, upward action provides a smooth energy-saving return motion. You will soon learn that airplane flight is based upon two laws and bird flight utilizes these laws as well.



Like an airplane's wing, there is a pressure difference between the upper and lower areas of a bird's wing. This creates a form of "Bernoullian lift." Also, when the bird changes its body angle slightly upward to its flight path, Newton's Third Law of Motion takes effect and this is an example of **dynamic lift** or "Newtonian lift." Like airplanes, birds need to approach and land slowly. A bird uses it tail feathers and its wing feathers to steer, brake, and produce **drag**, as well as lower speed lift. This greater lift, at a lower speed, allows the bird to land without getting hurt. The bird is a fascinating, natural flying machine and further study into its mechanism of flight is encouraged.

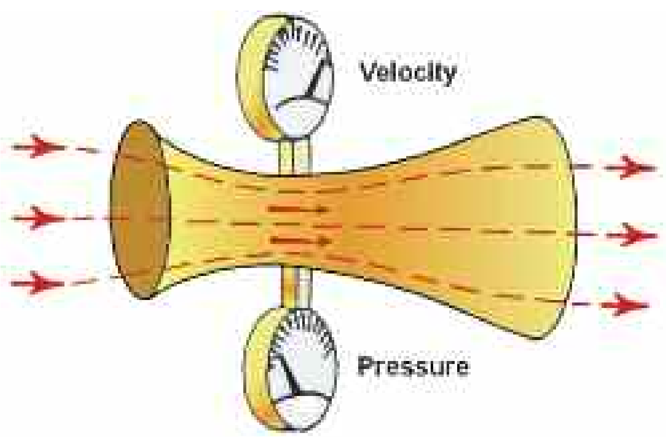


TWO GREAT SCIENTISTS NEVER FLEW, BUT . . .

Although they never attempted to fly, Dutch-born Daniel Bernoulli and Englishman, Sir Isaac Newton, are very important in the history of **aerospace**. The laws and principles they discovered laid the groundwork for the science of manned flight both in air (**aviation**) and in space. These laws helped develope many **aeronautic** accomplishments using the science of **aerodynamics**.

Daniel Bernoulli

Not as well known as Isaac Newton, but certainly one who holds an honored place in the history of aerospace science, is Daniel Bernoulli. His discovery of the relationship between pressure and fluids in motion became the cornerstone of the theory of **airfoil** lift. He found that a fluid, like air in motion, has a constant pressure. However, when that fluid is accelerated, the pressure drops. Using this principle, wings are designed to make air flow go faster over the top. This, in turn, causes the pressure to drop and the wing moves upward, against gravity.



Bernoulli found that the pressure of a fluid, like air, drops when it is accelerated. An example of this can be shown when air passes through a tube that has a restriction. This tube, known as a venturi tube, causes the air to accelerate when it passes through the middle. The pressure at the restriction drops. Notice the two gauges — the velocity gauge shows an increase and the pressure gauge shows a decrease. This is the secret of lift for flight that eluded mankind for centuries.

Daniel Bernoulli (1700-1782) Courtesy of the Royal Society, London, England

SIR ISAAC NEWTON

Isaac Newton received the highest honor when he was "knighted" for his work in science. That is why we call him "Sir" Isaac Newton today. He not only gave the world a mathematical explanation of gravity, he figured out how forces and motion are related to matter. He gave the world three laws that are still very much in use to this day:

1. An object at rest will remain at rest unless acted upon by an unbalanced, outside force.
2. A force acting upon a body causes it to accelerate in the direction of the force. Acceleration is directly proportional to the force and inversely proportional to the mass of the body being accelerated.
3. For every action, there is an equal and opposite reaction.

Sir Isaac Newton (1643-1727)
Courtesy of the Royal Society, London, England

Newton's Third Law is used to explain how an **aircraft** is lifted against the force of gravity. An example of this can be shown by sticking your hand out the window of a car traveling at highway speeds. Pointing your fingers forward (toward the direction the car is going) with your hand tilted slightly upward, your hand should rise. The oncoming wind becomes the action and the upward movement of your hand is the reaction. An airplane's wing acts like your hand. When it is angled slightly upward, it, too, receives some of its lift from the oncoming air. The airflow is the action and the reaction provides lift.

CAP Cessna 172 Skyhawk ready for lift-off – Photo courtesy of CAP member Alex McMahon

A NEW LOOK AT LIFT

There is an on-going argument concerning the role of Newton's Laws of Motion and the pressure differential theory of Daniel Bernoulli. This illustration, by cartoonist, Robrucha, is presented here with permission from the artist and *KITPLANES* Magazine.

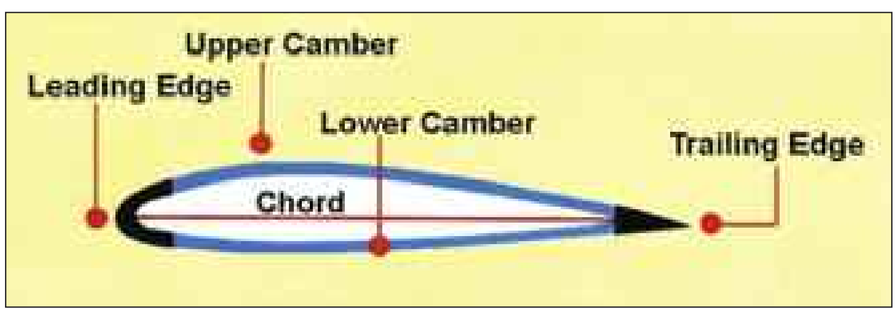
For years, there has been a widely accepted explanation on how a wing creates lift and makes the airplane take flight. Many textbooks, including ground school manuals for pilot training, explained the theory of lift like this: The upper surface of an airplane's wing (airfoil) is designed with a greater curvature or **camber** on the topside. This curved line causes the oncoming air to flow much faster over the upper surface. Using Bernoulli's Law for proof, it was stated: as the airflow speeds up, the pressure drops, and it creates a lower pressure as it passes over the top of the wing. With a lower pressure above, there has to be a higher pressure on the underside. Subsequently, the wing has nowhere to go but upward toward the lower pressure.

It was also taught that when the molecules of oncoming air split at the front of wing, they traveled over and under this airfoil and met at the back (trailing edge) of the wing at exactly the same time. This is known as **the theory of equal transit time.** Keep this in mind as it will be discussed later.

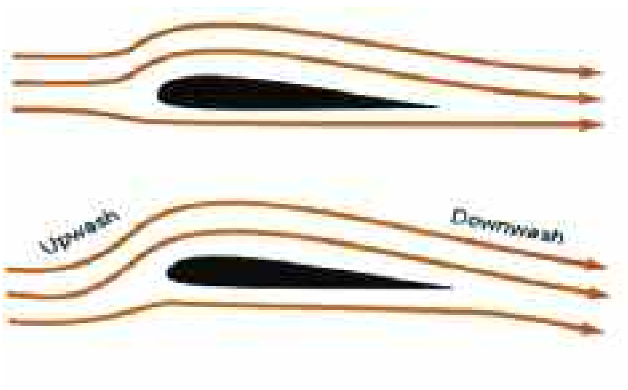
Newton's Third Law was also used in the explanation of how an airplane is lifted against the force of gravity. A classic example is this: When the airplane's wing is angled slightly upward, it receives **some** of its lift from the oncoming air. This example was explained in the text next to Newton's picture on page 6.

Both Newton's and Bernoulli's scientific laws have been used to explain how a wing lifts. These explanations were basically simple and something any elementary science book could handle. There was only one thing wrong. An explanation where Bernoulli's Law creates the lift, based on the shape of the airfoil, is not quite right. And— any explanation where Newton's Laws create most of the lift is also not quite right. The actual process of creating lift is very complicated. In the world of aerodynamic science, *there is an ongoing argument about how lift really occurs!*

Most every textbook correctly shows all of the parts of a wing. These include the leading edge, upper camber, lower camber, trailing edge, and chord. The actual shape of a wing (airfoil) has a beautiful, graceful form known as a tear-drop. Most airfoil designs are relatively flatter on the bottom.

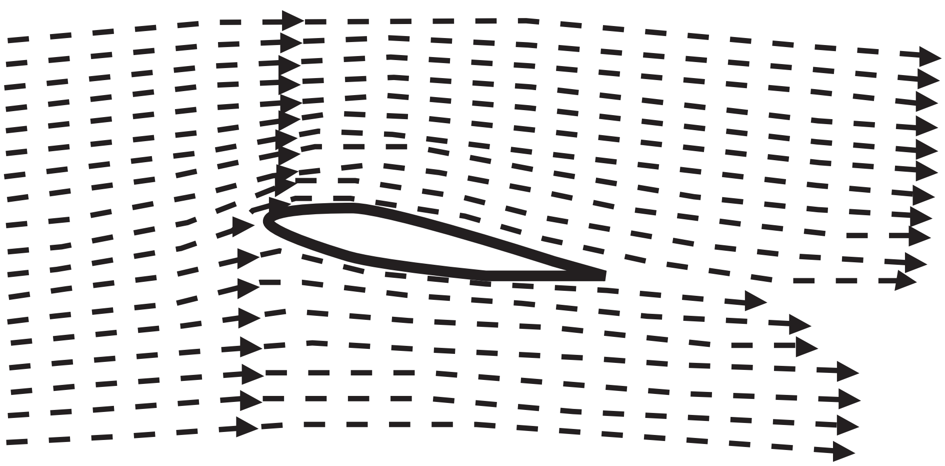


THE COMPONENTS OF A STANDARD AIRFOIL



Even when the air is calm around the **airport**, as an airplane moves forward on takeoff, it creates a "wind" that goes in the opposite direction. This air-in-motion is called the **relative wind.** At the beginning of this whole lifting process a lot of power is needed. This is provided by the propeller or a jet engine.

As air flows toward the wing, it splits at the **leading edge** and flows backward to join the underside air. Most traditional textbooks will say that the upper and lower air molecules will meet at the trailing edge at precisely the same moment. This is wrong. This explanation is based on the theory of equal transit time. In reality, the air traveling over the upper surface of the wing goes much faster and much farther than the underside airflow. Subsequently, the air flowing over the top goes beyond and downward. This is called **downwash** and creates a huge amount of dynamic force.



This illustration shows how the upper airstream goes beyond and downward compared to the airflow below the wing. Pick the two points just ahead of the leading edge and follow them backward.

THE WING CREATES A HUGE AMOUNT OF DOWN FORCE ON THE SURROUNDING AIR

When you look at a wing in cross-section, you will see the same tear-drop shape that was mentioned before. If you study it for a moment and imagine the air flowing around the wing during flight, you can readily see that the oncoming molecules of air at one point have to split. The upper flow has to bend upward and the lower flow bends to pass under the wing as shown in the diagram above.

Something else happens — the air flow tends to hug the wing. Air is a fluid like water and the flow tends to stick to the wing. As shown, on the following page, take a spoon and hold it under a flow of water from a faucet. Turn the bottom side of the spoon to the water flow and notice how the water hugs the spoon and then when it "exits" the tip of the spoon, it bends toward the center. This is called the Coanda effect.

In the drawing, above, that shows the streamlines of airflow around the wing, look at the molecules that are about to split. Now, follow the upper and lower molecules comparing both with your

This demonstrates the Coanda effect. The blue line is the direction the water would flow normally. When the spoon is inserted into the flow, the water "sticks" to the spoon and bends toward the tip.

eyes, and it will soon occur to you that the top flow is really "outrunning" the lower flow. Because of the higher speed of the top flow, and subsequent "back and down" action, the air passes the trailing edge wing and starts downward. This is where the Coanda effect comes into play. This "downwash" creates a huge amount of force and the subsequent reaction is what lifts the aircraft upward. The dynamic downwash force presses down so hard on the air, it causes the wing to lift. This enormous energy can be seen in the picture, below, of a Cessna Citation flying over a fog bank. The aircraft has actually pushed hard against the surrounding air and the reaction of the air is to lift the airplane. A **vortex** is visible behind each wingtip.

The dynamics of total lift are complicated, and it is almost impossible to make it "elementary simple" for this module. If you want to really get into the math and theoretical science of how lift occurs check out the following Internet sites, which are recommended for further aerodynamic study: www.grc.nasa.gov.www/k-12/airplane/downwash.html and http://adamone.rechomepage.com/index4.htm.

An article entitled "A Physical Description of Flight; Revisited"© by David Anderson & Scott Eberhardt can be "googled" on the internet and will give an excellent, in-depth coverage of flight science.

This picture dramatically shows airplane downwash. The Cessna Citation has just flown above a fog bank shown in the background. The downwash from the wing has pushed a trough into the cloud formation. The swirling flow from wingtip vortices is also evident. The picture was taken by Paul Bowens and the image was provided courtesy of Cessna Airplane Company.

This is the Civil Air Patrol Gippsland GA-8. When you look at this photograph, imagine what the plane is doing to the surrounding air. As the air passing over the wing speeds up, it passes behind the wing and creates a downwash. This puts a force against ALL of the air surrounding the wing ... and the airplane flies.

THE IMPORTANCE OF ANGLE OF ATTACK

When a pilot, or **aviator**, pulls back on the control stick, or yoke, the nose goes upward. In aeronautical terminology, it goes like this: when the pilot pulls back on the stick, the elevator goes upward and this causes the airplane to rotate around the lateral axis (the one that goes through the airplane wingtip to wingtip). The nose pitches upward and this subsequently causes the wing to also rotate around the lateral axis.

The pilot of this Canadair CRJ-700 has increased the angle of attack prior to takeoff. Angle of attack is also increased just before landing to slow the aircraft and provide an additional amount of control at low speed. Image courtesy of Adam Wright, First Officer, Atlantic Southeast Airlines.

It is easy to see that this upward movement of the leading edge causes the airflow coming toward the wing to make a much more dramatic "flow change." This also increases the dynamic forces against the underside of the wing. As a result of the higher "angle," or "angle of attack," a greater downwash is created as the flow exits the back of the wing. Thus, it can be stated that an increase in the angle of attack causes a substantial increase in the amount of lift created.

This increase in angle of attack explains how an airplane can fly upside down. Although the curvature of the wing is greatest (now) on the bottom of the wing, an increase in the angle of attack still creates the downwash and lift is maintained.

The Lockheed Martin F-35 Lightning II has the ability to take off and land vertically (STOV/L), or use an increase in the angle of attack in a conventional takeoff (CTOL). Image by Lockheed Martin.

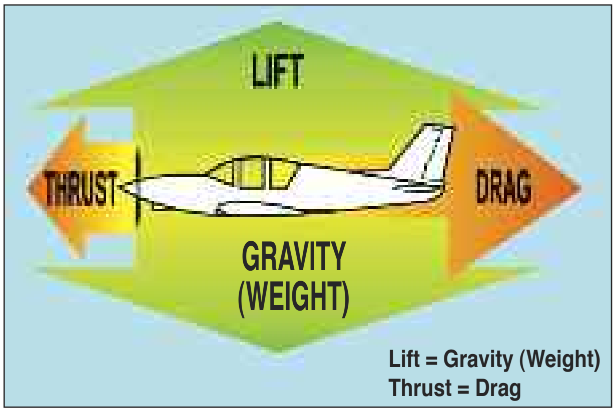
In everyday flying, angle of attack is changed many times during the course of a flight. It all begins at takeoff when a pilot has reached enough speed and then pulls back on the stick (or yoke). This causes the nose to pitch upward. This is shown in the images of the Canadair CRJ – 700 pictured.

The Lockheed Martin F-35 Lightning II Joint Strike Fighter (JSF) is a transformational weapon system that provides advanced survivability and lethality to a fighter-weapons platform.

This is the pilot's helmet for a Lockheed Martin F-35 Lightning II. An Australian Air Force pilot "models" this version. This helmet is needed because the JSF does not have a traditional heads-up display. Instead, the computerized symbology is displayed directly onto the pilot's visors, providing the pilot with cues for flying, navigating, and fighting with the aircraft.

THE FOUR FORCES ACTING UPON AN AIRPLANE IN FLIGHT

There are four forces acting upon an airplane in flight. They are **lift, gravity, thrust,** and **drag**. Each of these forces has an opposing force. The word "oppose" means to work against. Therefore, lift opposes gravity and drag opposes thrust. We will expand on these terms for better understanding.



Look at the diagram of the four forces, then imagine you can see them working on the Vixen airplane. (EAA)

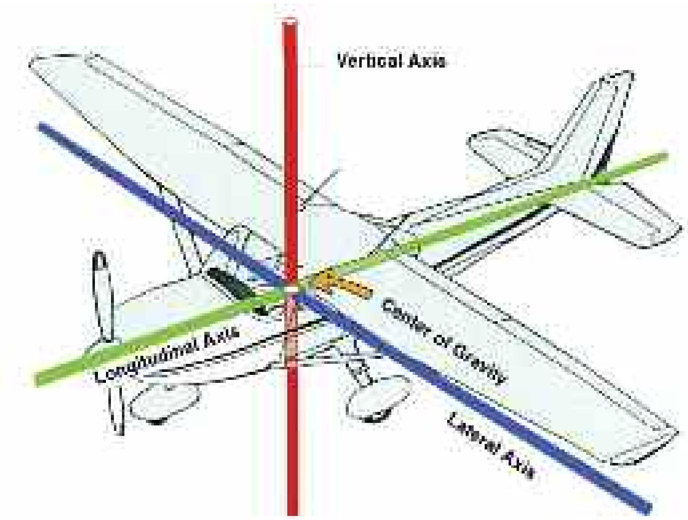
The Two Natural Forces

- **Drag** - The best way to understand drag is to imagine walking waist deep in a swimming pool. Now imagine what it's like to walk faster. It is difficult because of the drag of the water on your body. A similar resistance occurs when riding a bicycle against a strong head **wind**. Like water, air creates drag. Drag is a natural force that is common throughout all of nature, and is especially evident in flight.
- **Gravity** - There is a natural force which pulls everything toward the center of the Earth. This is the force of gravity, and, on Earth, we speak of that force as being one "G."

The Two Artificial Forces

- **Thrust** - This is a force that pulls or pushes an airplane forward through the air, and it opposes drag. In some airplanes, thrust is provided by a propeller; in others, it is provided by a jet engine. This force is artificial because it takes a mechanical device, like an engine and propeller, to generate it.
- **Lift** - This, also, is an artificial force because it requires a mechanical device to create the pressure changes discussed in Bernoulli's Law. Pressure differential creates lift. To put this into practical terms, when an airplane is ready for takeoff, the pilot adds power and the machine moves forward. The relative wind starts to flow under and over the wings. The wings (a mechanical device) are being forced to move through air (a fluid).

THE THREE AXES



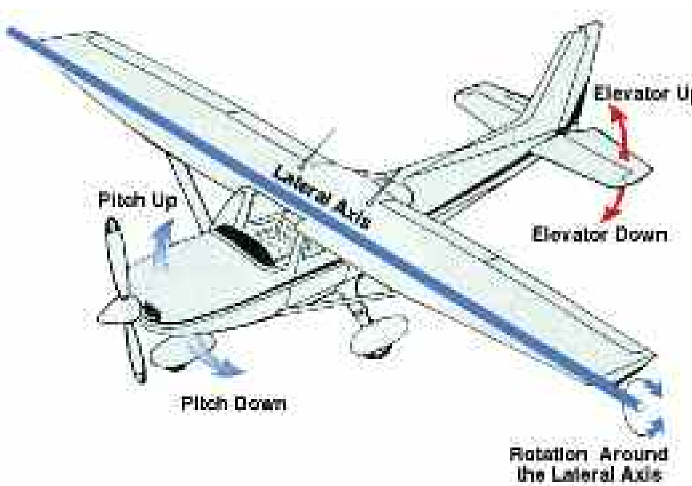
The Three Axes of an Airplane

Imagine that you are an aeronautical engineer and one of your jobs is to suspend an airplane from a cable so that it will hang perfectly level in all directions. For the sake of illustration, let's say that you are going to do this experiment in a large building area, like a hangar or a gymnasium. Somewhere up high, you would hook the cable to one of the ceiling supports. The other end would be hooked to the airplane at precisely the right point where it would hang level. This cable line would be known as its **vertical axis** (the red line).

Now, visualize a line that goes from wingtip to wingtip and passes through the center where the cable suspends the airplane. This side to side line is called the **lateral axis** (the purple line). Imagine yet another line that passes through the nose and ends at the tail. This line also passes through the cable that is suspending the airplane. This nose to tail line is known as the **longitudinal axis** (the green line).

If you hooked your cable at the point where all three of these "axes" come together, that point is called the **center of gravity** (denoted by gold arrow). Refer to these axes, as we will continue to discuss them. (See associated Activity One at the end of the chapter.)

Airplanes Can Only Move In Three Directions



Rotation around the lateral axis is called pitch and the elevator causes this motion. When the elevator moves up, the nose pitches up. When the elevator moves down, the nose pitches down.

In flight, an airplane can only move in three directions; i.e., nose right/nose left, roll right/roll, and left nose up/nose down. An example: if you walked out to the end of the wing of this suspended airplane and pushed up or pulled down on its wingtip, it would rotate around the longitudinal axis. Rotation around this axis is called **roll.** (See associated diagram on page 14.) If you went back to the tail and moved it up and down, the airplane would rotate around its lateral axis, as shown in the illustration to the right. This motion is called **pitch.** If you moved the tail from side to side, this would be a rotation around the vertical axis and is called **yaw.** (See associated diagram on next page.) Thus, flight is said to be three dimensional. So, how does a pilot get the airplane to move in these three dimensions? It's done by manipulating the moving parts on the plane with the inside control stick (yoke) and the rudder pedals. By using the dynamic forces of the air as they rush over the **control surfaces** of the airplane, the airplane flies. (Refer to labeled airplane parts on page 2, and the descriptions of these parts, as follow on the next page.)

The Elevator Is Hinged To The Horizontal Stabilizer

The horizontal stabilizer is fixed and doesn't move. It gives the airplane stability. The elevator is attached to the horizontal stabilizer and moves up and down. Movement of the elevator pitches the nose up or down in a rotation around the lateral axis.

Elevator assembly

The Stabilator

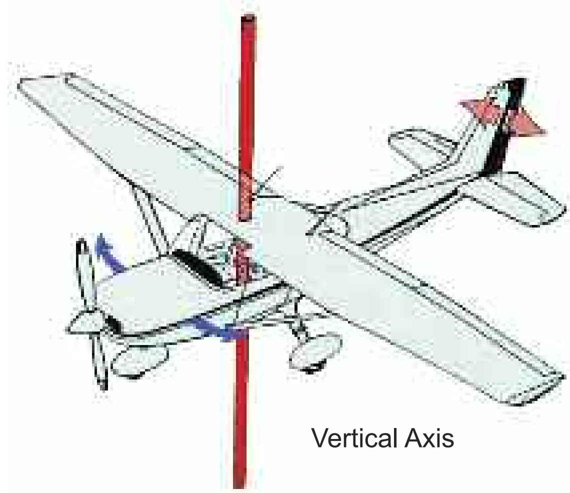
On some aircraft, the horizontal stabilizer and the elevator are one. Engineers call this a "stabilator," and it works by changing the angle of attack. The stabilator is a very effective method of controlling pitch. When the pilot pulls back on the control yoke (or stick), the stabilator's leading edge goes down. This creates a "negative" angle of attack and the low pressure increases on the bottom. When the stabilator is moved, it causes a rotation around the lateral axis and the nose is pitched up or down.

Stabilator assembly

Nose Right, Nose Left

When the pilot wants the nose to go left or right, he/she has to move the rudder pedals located on the floor of the cockpit. When the right rudder pedal is pushed forward, this moves the rudder to the right. The dynamic force of the air causes the tail of the airplane to move left and the nose to go to the right. This movement is around the vertical axis. The nose right, nose left motion is called yaw.

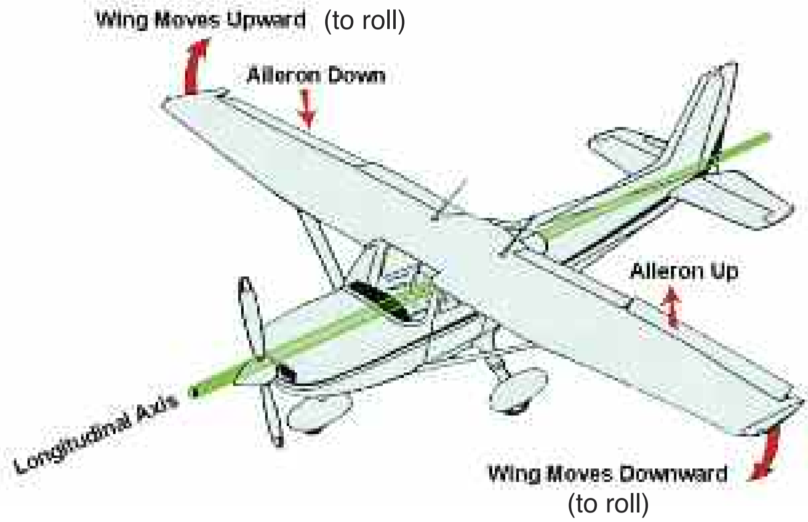
Vertical stabilizer and rudder assembly



Rudder pedals used to created vertical stabilizer movement in the rudders create yaw rotation.

Wingtip Up, Wingtip Down

If a pilot wants the wings to move up or down, he/she rotates the control yoke to the right or left. Out on the ends of the wings are located control "surfaces" called **ailerons**. When one aileron moves downward, the other one, on the opposite wing, moves upward and vice versa. The airplane then rotates around the longitudinal axis. This movement around the longitudinal axis is known as **roll**.



Flaps And What Are They Used For

When a control surface is moved, especially on a wing, some people will say that the pilot is "moving the flaps." In fact, many uninformed people think that any moveable control surface on an airplane is called a "flap." So what are the real flaps and what do they do?

The Flaps on a Cessna Skyhawk

In the photograph of the Fowler Flaps, to the right, notice that the trailing edge of the wing is down. It looks somewhat like the whole backside of the wing has dropped. This is somewhat true — the inboard portion of this airplane's wing did go down. From an aerodynamic point of view, study the photograph and visualize the upper camber of the wing, starting at the leading edge and going all the way back to the trailing edge. With the flaps down, the curvature of the upper camber is dramatically increased and so is the wing area. The flaps shown on this Cessna are known as Fowler Flaps.

Right aileron and flap of a Cessna

When the flaps are down, it causes an increase in both the upper camber and wing area. This will substantially increase lift. So there you have the answer. The flaps actually increase lift so that an airplane can fly slower and still maintain flight. Flaps are especially useful in landing, where it is desirable to touch the ground at a minimum speed. Flaps are also used during takeoff and this allows the pilot to decrease takeoff distance. And, finally, flaps increase drag. They act like big "doors" that open into the airstream. During one of your orientation flights, ask the pilot to demonstrate the use of flaps. Note the airspeed when the flaps come down. You will also feel a change in the airplane and hear the air rumble around the flaps. The airplane will rise (increase lift) and the wind will buffet (drag) the flaps. They are very effective in what they do. (See associated Activity Two at the end of the chapter.)

THE AERODYNAMICS OF A PROPELLER

When you examine a propeller closely, you soon discover that it is shaped like a wing on each side of the center, or hub. The reason for this airfoil shape is obvious, it is a wing. It is a wing designed to "lift" forward creating a force called **thrust**.

As the propeller rotates, its leading edge moves through the air and this motion creates a relative wind. As this rotational relative wind moves around the curved surface of the propeller blade, a low pressure is created. This low pressure is a "forward lift," and given enough power, the entire airplane will move forward into this area of lower pressure.

The propeller blade

The numbers on the propeller photograph to the right are significant points in the aerodynamics of a propeller. (1) This is the hub. Bolts go through this hub and fasten the propeller to the engine. (2) Notice that this part of the blade is thick and narrow. Note also that the angle, called the angle of incidence, is quite high. If you can imagine this propeller going round and round at a certain speed, other than the hub, this point will be the slowest. Low pressure, or lift, is created by a high angle of incidence and greatly curved camber. (3) The blade has a longer chord and greater area. The angle of incidence has slightly decreased and, at this point, the speed is much greater. (4) The angle of incidence is considerably less than near the hub. The chord is longer and the speed is higher. (5) Out at the tip, the speed is tremendous so there is a smaller chord, smaller angle of incidence, and a smaller area. If you think in terms of the four methods of increasing lift, the shape of the propeller begins to make sense.


Starting at the hub, you can see how the blade changes in angle, chord, and area on this restored Piper Cub. Just like a wing, the rotating propeller harnesses the energy of the air and converts it to thrust.


Once the engineers figured out the right propeller to harness the power of its engine, this WWII P-47M Thunderbolt became one of the fastest fighters in the war.

In the history of one of America's most important World War II aircraft, the P-47 Thunderbolt, it tells how engineers at Republic Aircraft had a difficult time getting the right propeller for the huge Pratt & Whitney R2800 engine. Eventually they found the right combination and the "M" version of this aircraft reached almost 500 miles per hour.

UAV – UNMANNED AERIAL VEHICLES

Two Predators are being launched from
Creech Air Force Base near Indian Springs, Nevada

MQ-9, Reaper UAV

They look a bit strange, and it becomes immediately apparent that no one is at the controls when a UAV passes by on takeoff. These "UAVs," stand for *Unmanned Aerial Vehicles*. In a combat zone, if the enemy spots one, it is probably already too late to react. Pilots sitting in a control center 7,000 miles away know exactly who the enemy is and where they are. The pilot controlling the UAV only has to acquire the target and destroy it. These incredible machines have just come into a position of high regard by the U.S. military and they are feared by our enemies.

One of the centers for UAV operation and control is at Creech Air Force Base in Indian Springs, Nevada. For several years, the UAVs were used mostly for reconnaissance (a preliminary, or exploratory survey of an area to collect information), but as conflicts escalated, they have taken on a combat role. Of these predators, one version is known as the Reaper MQ-9, and is one of the most effective combat aircraft ever to go to war. CAP uses the "surrogate predator" for increasingly important missions for non-combat reconnaissance missions. (CAP does not do surveillance. Local authorites do surveillance, as described on the next page.)

In 2006, the USAF announced that it had a UAV capable of hunting and destroying enemy activity. It was a modification of an earler UAV series and was designed to carry as many as 14 Hellfire anti-tank missiles. The MQ-9 UAV can carry bombs and precision-guided missiles to the battle zone. The aircraft has a ceiling of 50,000 feet and a cruise speed of 260 knots. One of the most notable features is its ability to "loiter" in the target area for as much as 14 hours.

In order to give the reader a better understanding of the UAV and its role in the U.S. Air Force inventory, the following will focus on the role of the MQ-9 as it currently exists.

The MQ-9 is a variant of the original UAV used by the Air Force MQ-9 *Predator*. It is manufactured by the General Atomics Aeronautical Systems and is used as a high-altitude, long range, long endurance combat aircraft. The primary mission is that of surveillance (a close watch, or supervision, of an area after reconnaissance, or "recognition" of something in the area).

With smoke from Lake Arrowhead, CA, fires in the background, the NASA Ikhana UAV heads out on a wildfire imaging mission.

The MQ-9 has a 950 horsepower (hp) turbopropeller engine. There are several terms used in this new aerospace technology and they include: UAV - Unmanned Aerial Vehicle; UAS - Unmanned Aerial System; and RPV - Remotely Piloted Vehicle. All of these terms are used in basically the same context.

Although the MQ-9 can fly on pre-programmed flight plans by itself, it is constantly controlled by flight crews located at Air Force installations known as GCS, or Ground Control Stations. By the end of 2009, the U.S. Air Force had a total of 195 Predators and 28 Reapers in its inventory.

NASA has also been using a UAV in its continuing research efforts. One example, the *Ikhana,* has been extensively used in combating wild fires in California. This demonstrated that UAV's are extremely valuable in the private sector, as well as in military service. (See associated Activity Three at the end of the chapter.)

THE BIG BIRD – GLOBAL HAWK

Another UAV that has been used in the combat arena is the Global Hawk. The image shown is a Grumman RQ-4 in route to record intelligence, surveillance, and reconnaissance data. Because of its large coverage area, the remotely-piloted aircraft has become a useful tool for recording data and sending it to warfighters on the ground.

The Global Hawk is built by Northrop Grumman and is primarily used by the USAF


A ground control station crew performs post takeoff checks after launching an earlier Predator MQ-1 from Ballad Air Base in Iraq. USAF image by Master Sergeant Steve Horton

as a surveillance aircraft. It is equipped with Synthetic Aperture Radar that penetrates heavy weather, including sand storms. It has the ability to survey over 40,000 square miles in a day. Specifications include:

- Empty weight is 9,200 lbs
- Payload is 1,900 lbs for the RQ-4 and 3,000 lbs for the RQ-4B
- Maximum gross take-off weight is 25,600 lbs (the RQ-4B version weighs 32,250 lbs)
- Engine is a Rolls Royce North American AE3007H turbofan
- Loiter on station is 24 hours
- Loiter velocity is 343 knots TAS
- Maximum altitude is 65,000 ft
- Wingspan is 116.2 ft (RQ-4B - 130.9 ft)
- Length is 44.4 ft (RQ-4B - 47.6 ft)
- Height is 15.2 ft
- Length is 44.4 ft
- Wing area is 540 ft^2
- Wing aspect ratio is 25:1

(See associated Activities Four, Five, and Six at the end of the chapter.)

The deadly-looking Global Hawk is on an Air Force mission somewhere in the world. USAF photo.

ACTIVITY 1 SECTION

Activity One -
The Soda Straw Three Axis Demonstrator

Purpose: This activity will demonstrate how the three axes of flight in an airplane works.

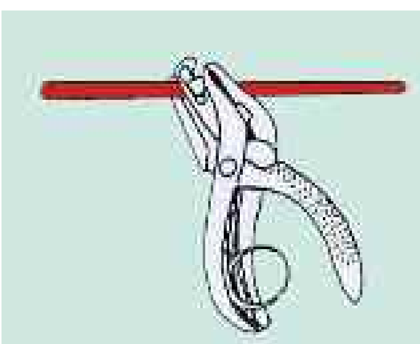
Materials: 3 soda straws and a hand-held, single-hole, paper punch

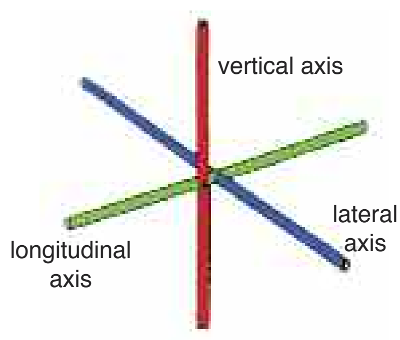
Procedures:

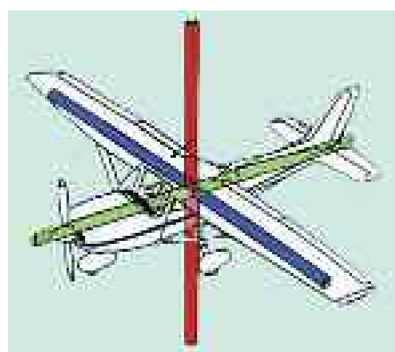
1. Punch 2 holes in the center of one of the straws. These holes should be near the center and perpendicular to each other.
2. Pull 1 soda straw through 1 of the holes. You now have two axes.
3. Insert the third soda straw into the remaining hole. What you now have is a three axis demonstrator. Refer to top illustration on page 2, which displays labeled airplane parts. Now, imagine that your three axis demonstrator is an "airplane." If you hold one straw on each end, that's your "wings." If you rotate the straw, you are pitching the demonstrator around the lateral axis. If you grab the vertical straw and rotate it, you are "yawing" the demonstrator to the left and right. And finally, if you grab the "nose" and "tail" ends of the straw, and rotate it, you are "rolling" the demonstrator, such as tilting from side to side.

(Note: You can also attach your axis demonstrator to a balsa, paper, or other model airplane for the procedures above.)

Summary: The three axes of flight in an airplane pass through the airplane's center of gravity, which is that point located at the center of the airplane's total weight. The longitudinal axis (green straw in diagram) extends lengthwise through the fuselage from the nose to the tail. Movement of the airplane around the longitudinal axis is known as roll and is controlled by movement of the ailerons. The lateral axis (blue straw in diagram) extends crosswise from wingtip to wing tip. Movement of the airplane around the lateral axis is known as pitch and is controlled by movement of the elevators. The vertical axis (red straw in diagram) passes vertically through the center of gravity. Movement of the airplane around the vertical axis is yaw and is controlled by movement of the rudder.







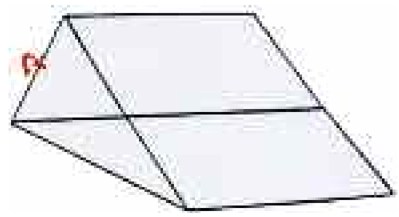
The three-axis soda straw demonstrator was developed by Dee Ann Mooney, Civil Air Patrol member and math teacher at Big Sky High School, Missoula, Montana.

Activity Two -
Folding, Flying, and Controlling the Flight of a Paper Airplane

Purpose: This activity teaches, by modeling, about a delta wing configuration airplane and the control surfaces of this paper airplane by using experimentation and the inquiry method.

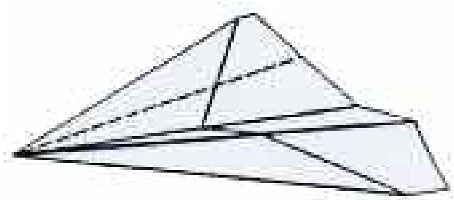
Materials: a sheet of standard printer paper and scissors

Procedures: Follow the instructions as outlined in the diagrams



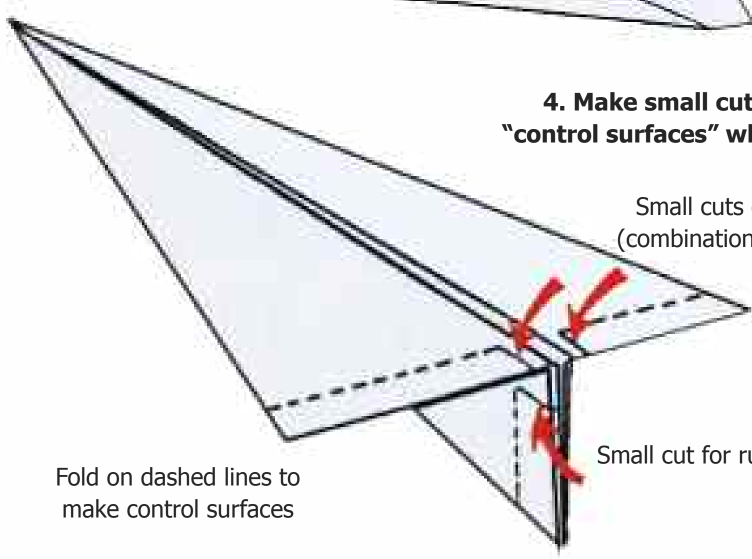
1. First, a sheet of standard printer paper is folded in half, "hot dog style." Then it is folded back, as shown. The two upper edges fold to the center.

2. A portion of the outer edge is folded to the center. Make sure the both sides are equally folded.



3. The wings are folded outward and the two halves are held together either by a staple or tape.

4. Make small cuts, as shown, to manipulate the "control surfaces" which will control direction of flight.

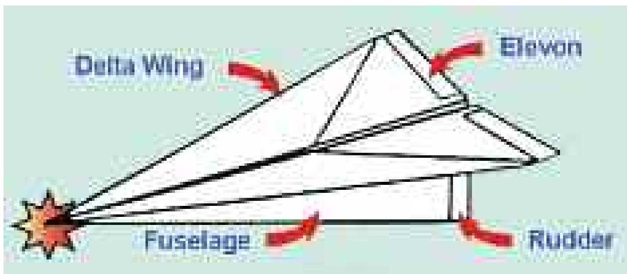


5. Fly your airplane to create the three directions of flight: nose up/nose down, nose right/nose left, roll right/roll left. How do you accomplish this? Refer to the directions in chapter 1, found on pages 12-14, to adjust movable control surfaces. Also, refer to further directions on pages 21-22. The questions at the end are suggestions on how to expand this activity.

Summary: The control surfaces of this paper airplane are the elevons (a combination of a conventional elevator and ailerons) and the rudder (which causes the airplane to yaw left or right). When the maneuvers are correctly performed, the conclusion can be reached that the paper airplane is similar to a real airplane.

Components of a Paper Airplane

The paper airplane has components just like a real one. The wings of our activity model have a "delta" shape; i.e., they come to a point at the nose like an arrowhead. At the back of the delta wing you were asked to make two cuts and to become control surfaces known as **"elevons."** This is a combination of conventional **elevators** and **ailerons.** Since the elevator makes the airplane's nose go up and down, both of the paper airplane's elevons in the up position will make the nose pitch up when you throw it. If one elevon is down and the other is up, the actions of the ailerons are enacted and the aircraft will spiral through the air when thrown. This motion is called roll.

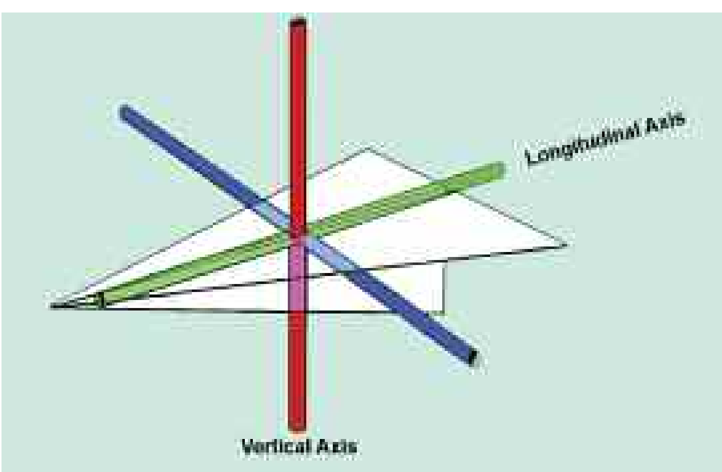


Don't throw a sharp-nosed paper airplane at anyone (might want to fold and tap the point inward for safety).

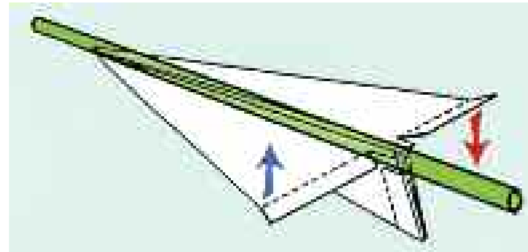
The paper airplane has a delta wing configuration. The famous Concorde had the same design.

The Three Axes of a Paper Airplane

Now, let's mark the paper airplane to match a real one. A line drawn from nose to tail going through the center is called the **longitudinal axis**. A line drawn from side to side passing through the center is called the **lateral axis**. A line drawn down through the center from top to bottom is called the **vertical axis**. All of these lines (axes) will pass through the exact center of the paper airplane; this point is called the center of gravity. To find the center of gravity, get a piece of thread, some household tape, and see if you can make it hang perfectly level in all directions.

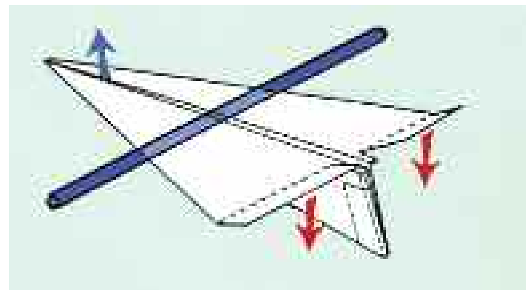


Making It Roll



The first paper airplane flight maneuver is an easy one. Simply put one elevon up and the other elevon down. Throw the paper airplane and it should spiral through the air rolling several times.

Making It Pitch



You can make the nose of the paper airplane pitch up or down by adjusting the elevons. If you put both elevons up to a 40 degree angle, it should fly forward, pitching upward, and then stall. Once it stalls, the nose will pitch downward and it will head for the floor. You can experiment with various elevon settings so that the aircraft will stall several times before hitting the floor. These multiple stalls are called **secondary stalls**.

One of the more difficult maneuvers is to make the paper airplane land gently. Try this experiment with various elevon settings. Put the elevons up maybe 10 degrees and give it a toss. It may glide forward or roll slightly. If this happens, adjust each elevon until it flies straight. Then fold the elevons a few more degrees and, eventually, your paper airplane should glide in for a very smooth landing.

Make a “runway” on the floor using masking tape or a piece of cardboard. This runway should be about 4 feet long and 1 foot wide. Stand about 20 feet from one end of the runway and try to “land” your paper airplane on the surface. If you find this too easy, back away another 20 feet and give it a try.

Be A Paper Airplane Test Engineer With These Suggested Activities

1 What is the length of your paper airplane in inches and centimeters?
2. What is its exact wingspan?
3. Can you determine the chord of a delta wing?
4. How much does your plane weigh in milligrams, grams, kilograms, and ounces?
5. Where is the exact center of gravity?
6. Measure the greatest distance it will fly in meters and feet.
7. At what carefully measured point in its flight does it stall?
8. Can you make it fly in a long, wide turn?
9. In competition with another person, “Calling Your Shot” is a fun activity.
   a. Call for a spot landing.
   b. Call a pitch and make the aircraft descend into a trash can.
   c. Call a roll and make it fly through a hoop.
   d. Call a stall to a spin.
10. Develop a computer program for the flight test of a paper airplane.

Activity Three -
MQ-1 Predator

Purpose: Build a Predator and observe how it flies.

Materials: foam board or meat trays, hot glue gun, spray glue, snap knife, pennies, and copy of Predator cut outs (template) on the next page

Procedures:

1. Attach the page of cut outs with spray glue to the foam board or meat tray.
2. Cut out the designs.
3. Use the red-dashed lines that indicate where to put glue or hot glue used to bond together the pieces of the aircraft.
4. Fly your airplane.
5. Experiment with different nose weights until the plane flies, as desired.

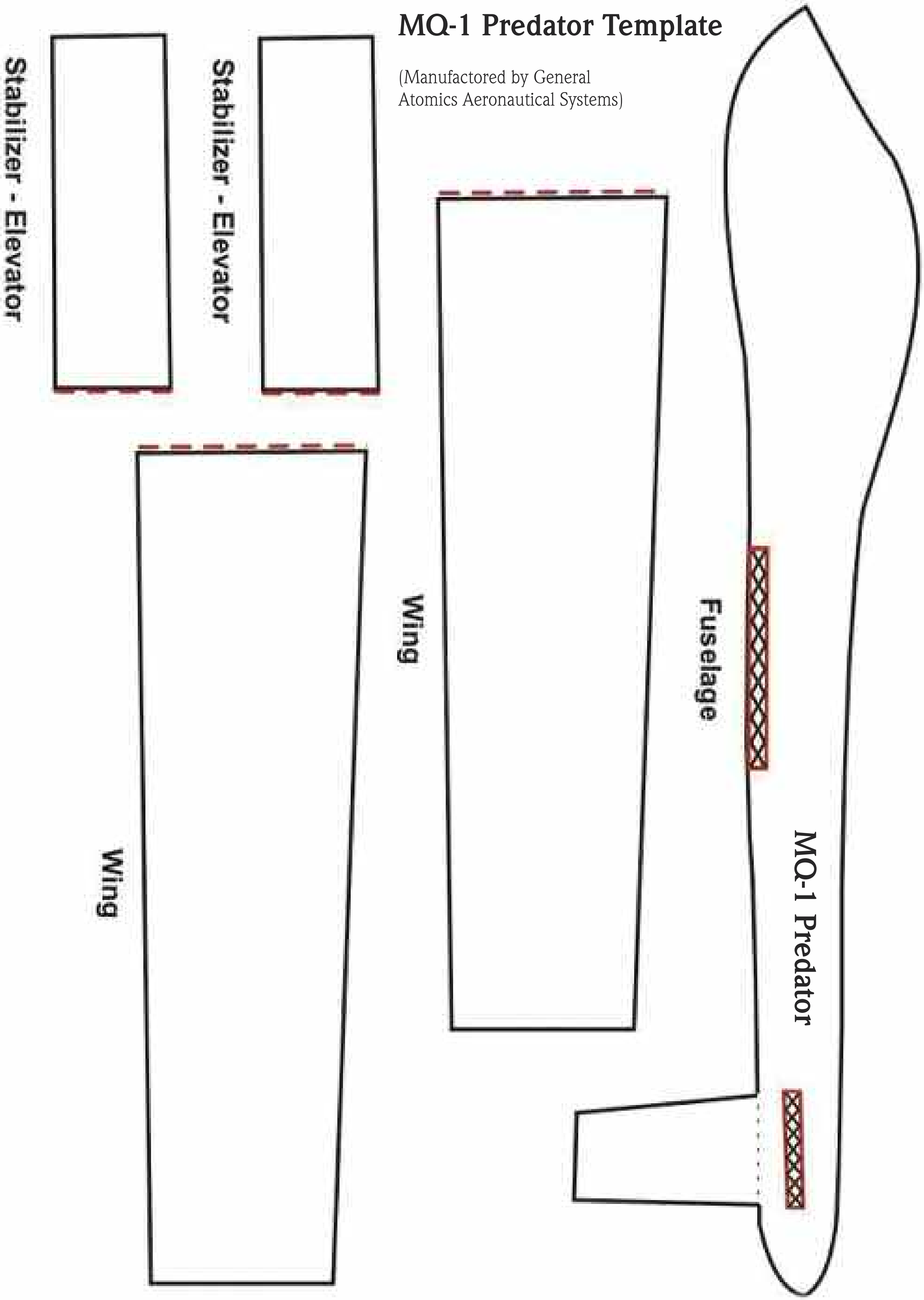
Notes: Foam works very well for making flying models. It is strong, very light weight, and inexpensive. Styrofoam meat trays from the grocer work well, and are free! The following recommendations work well for a group activity:

- It is recommended that you use a low-tack spray glue, such as 3M Spray Mount™ to bond the template to the foam board or styrofoam meat tray.
- Use a hobby knife or a "snap knife" to cut out your foam pieces. (Adult supervision needed.)
- Hot glue guns have an adhesive that works very well on foam board for attachment of wings and stabiliser elevators.
- There is also foam "glue" that is available in craft stores like Hobby Lobby™ and some hobby shops. This works well, but takes longer to dry. You might ask for "Helmar" foam glue if you need a brand name. (It also works well on cardstock, for other activites.)
- It is recommended that you build one complete side of the model first. Get it perfect and then attach the opposite pieces for alignment.
- Foam flyers also need nose weight to better stabilize or balance the plane for better control. Using hot glue, you can experiment with pennies, dimes, or gem clips until the desired stabilization point is achieved.

Summary: The General Atomics Aeronautical Systems MQ-1 Predator is an unmanned aerial vehicle (UAV) which the United States Air Force (USAF) describes as a MALE (medium-altitude, long-endurance) UAV system. More information was discussed on page 17 to describe its purpose in use. Learning to fly this model, while experimenting with nose weights and amount and direction of thrust use to fly it, can aid in better understanding of the complexities of maintaining proper balance to achieve and maintain flight.

MQ-1 Predator Template

(Manufactored by General
Atomics Aeronautical Systems)



Activity Four -
Northrop Grumman RQ-4 Global Hawk

Purpose: Build a Global Hawk and observe how it flies.

Materials: foam board or meat trays, hot glue gun, spray glue, snap knife, pennies, and copy of the Global Hawk cut outs on the next page

Procedures:

1. Use spray glue to attach the cut outs (templates) on your foam board or meat tray.
2. Cut out the designs.
3. Use the red-dashed lines that indicate where to put glue or hot glue used to bond together the pieces of the aircraft.
4. Fly your airplane.
5. Experiment with different nose weights until the plane flies, as desired.

Notes: Foam works very well for making flying models. It is strong, very light weight, and inexpensive. Styrofoam meat trays from the grocer work well, and are free! The following recommendations work well for a group activity:

- It is recommended that you use a low-tack spray glue, such as 3M Spray Mount™ to bond the template to the foam board or styrofoam meat tray.
- Use a hobby knife or a “snap knife” to cut out your foam pieces. (Adult supervision needed.)
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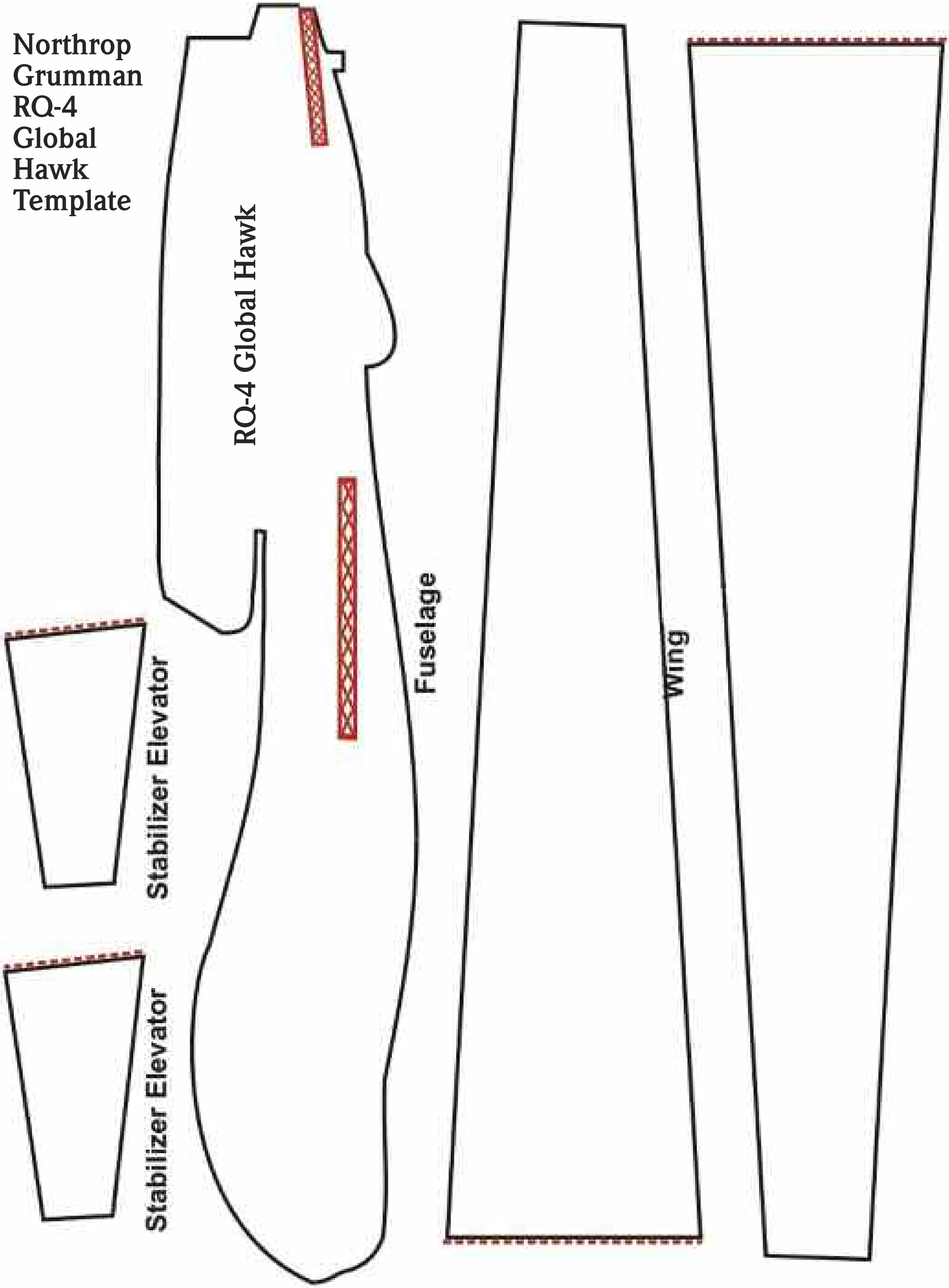
- It is recommended that you build one complete side of the model first. Get it perfect and then attach the opposite pieces for alignment.
- Foam flyers also need nose weight to better stabilize or balance the plane for better control. Using hot glue, you can experiment with pennies, dimes, or gem clips until the desired stabilization point is achieved.

Summary: The Northrop Grumman RQ-4 Global Hawk, as discussed on page 17, is a remotely-piloted aircraft used by the United States Air Force and Navy as a surveillance aircraft. Learning to fly this model, while experimenting with nose weights and amount and direction of thrust use to fly it, can aid in better understanding of the complexities of maintaining proper balance to achieve and maintain flight.

Northrop Grumman RQ-4 Global Hawk Template



Activity Five -
The Race to the Top!

Purpose: This activity is a contest between the flying models built in activities 3 and 4, the Global Hawk and the Predator, to learn about different aircraft ad how their designs and performance are different.

Materials: pre-prepared airplane models for contest

Procedure:

1. This is a contest using the pre-built Global Hawk and Predator foam models.
2. Divide the participants into two groups; one group using the Global Hawk model, and the other group using the Predator model.
3. Test Flight Phase- Each participant gets 5 minutes to "test and tweak" their foam models. This can be done in any open area, such as a gym or outdoors. Weights can be added and/or adjusted, as needed, to prepare for the contest.
4. Contest Phase- Each participant flies his/her foam model to determine and record the following on the Contest Form on the bottom of this page:
   a. Longest distance
   b. Spot landing accuracy
   c. How much of a circle made when flying with angular degrees
   d. How to fix the elevators so it causes the nose to go up and stall the aircraft
5. To determine team winner of contest, compare 2 categories: distance (part a above) and sum total of parts b, c, and d above. If one team is highest in both categories, there is a clear team winner. If each team wins in one category, winners could be declared for each category. Or, there could be a "fly off" between the top distance scorer on each team with the longest distance winner "breaking the tie."

Summary: In this activity the contest provided ways to test the construction of the models from Activities 3 and 4. This activity will also promote the inquiry method to solve problems based on desired results and the variables that can cause such results.

Contest Form for: ________________________________ **Company President:**________________________

Company Members:____

Participant's Name	Type of Aircraft	Distance	Accuracy	Degrees of a Circle Flown	How was Stall Accomplished	Total Points
Record Averages in this Row						

Find the average for each category of competition except Stall column and record on the last row.

Activity Six -
Build the SR-71 Blackbird

Purpose: This activity teaches how to build a model of the SR-71 Blackbird, fly it as a foam glider, and demonstrate an understanding of the words fuselage (the body of the plane) and nacelle (the enclosed portion covering the engine outside the fuselage).

Materials: piece of 1¾" outside diameter foam pipe tubing cut to a length of 14 inches (found at local hardware or super center stores), two pieces of foam tubing cut to 4 inches, a foam meat tray, a #64 rubber band, a nylon cable tie, a metal washer, tape, spray-on glue, hot glue gun, Exacto knife or other cutting device (adult supervision needed), and copy of SR-71 Blackbird template found on page 29

Procedure:

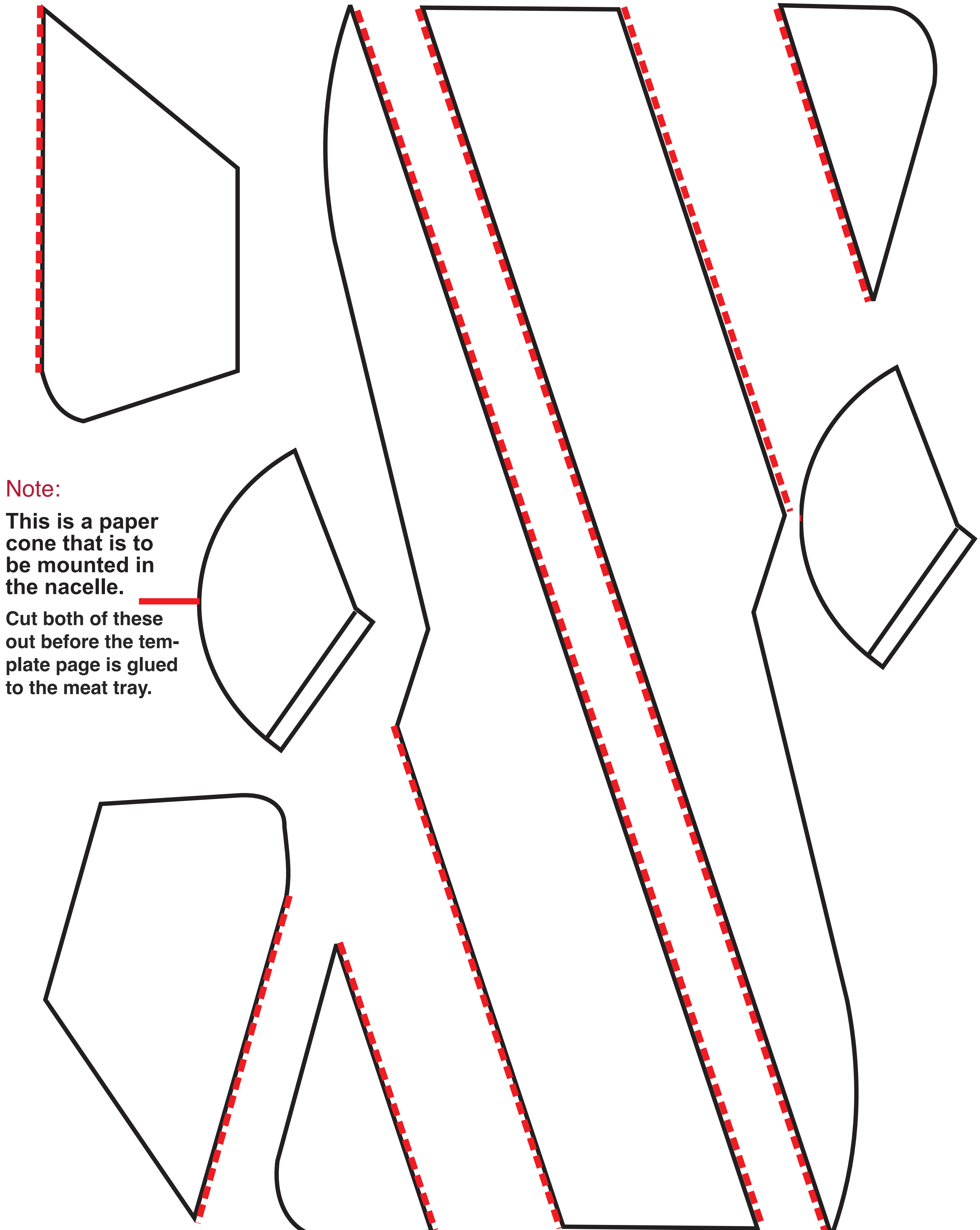
1. Cut out paper cones on template sheet and hold for later use.
2. Attach the remaining template to the meat tray with spray-on glue.
3. Cut out the wings and fins templates.
4. Hot glue the wings and fins to the long foam tubing (fuselage) and the 2 shorter foam tube pieces (nacelles), as shown in the illustration on page 30. (* It works best to use hot glue on the wings and fins, as opposed to on the foam tubing, as the hot glue melts the foam tubing.)
5. Roll the paper cones pieces into a cone shape that will fit inside the nacelles and tape shut. Hot glue these to the nacelle, as shown in the illustration on page 30.
6. Tie the rubber band in and through the hole of the washer to "lock" in place.
7. Insert the washer/rubber band into the top of the fuselage, letting about an inch of the rubber band hang out the top (which will become the nose section of the aircraft).
8. Pull a cable tie around the nose and cinch it down as tight as possible. Clip the remaining tail of the cable tie. Put a drop of hot glue on the sharp cut edge of the cable tie to avoid being cut by the sharp edge.
9. To launch, put one thumb in the tail pipe and stretch the rubber band with the other hand and let it fly!

Summary: This chapter discussed reconnaissance aircraft, albeit unmanned aerial vehicles (UAVs) used for surveillance and reconnaissance. Thus, it was logical to add another fun aircraft to make and fly, the SR-71 Blackbird, which was unofficially named the "Blackbird." The Blackbird was developed as a long-range strategic reconnaissance aircraft capable of flying at speeds over Mach 3.2 and 85,000 feet. The first SR-71 to enter service was delivered in 1966 and was retired in 1990. However, the USAF still kept a few SR-71s in operation up until 1998, after a few were brought back to service in 1995. NASA Drysden's Center at Edwards AFB, CA flew the SR-71 from 1991 until the program was cancelled in 2001. On 15 December 2003, SR-71 #972 went on display at the Steven F. Udvar-Hazy Center in Chantilly, Virginia.

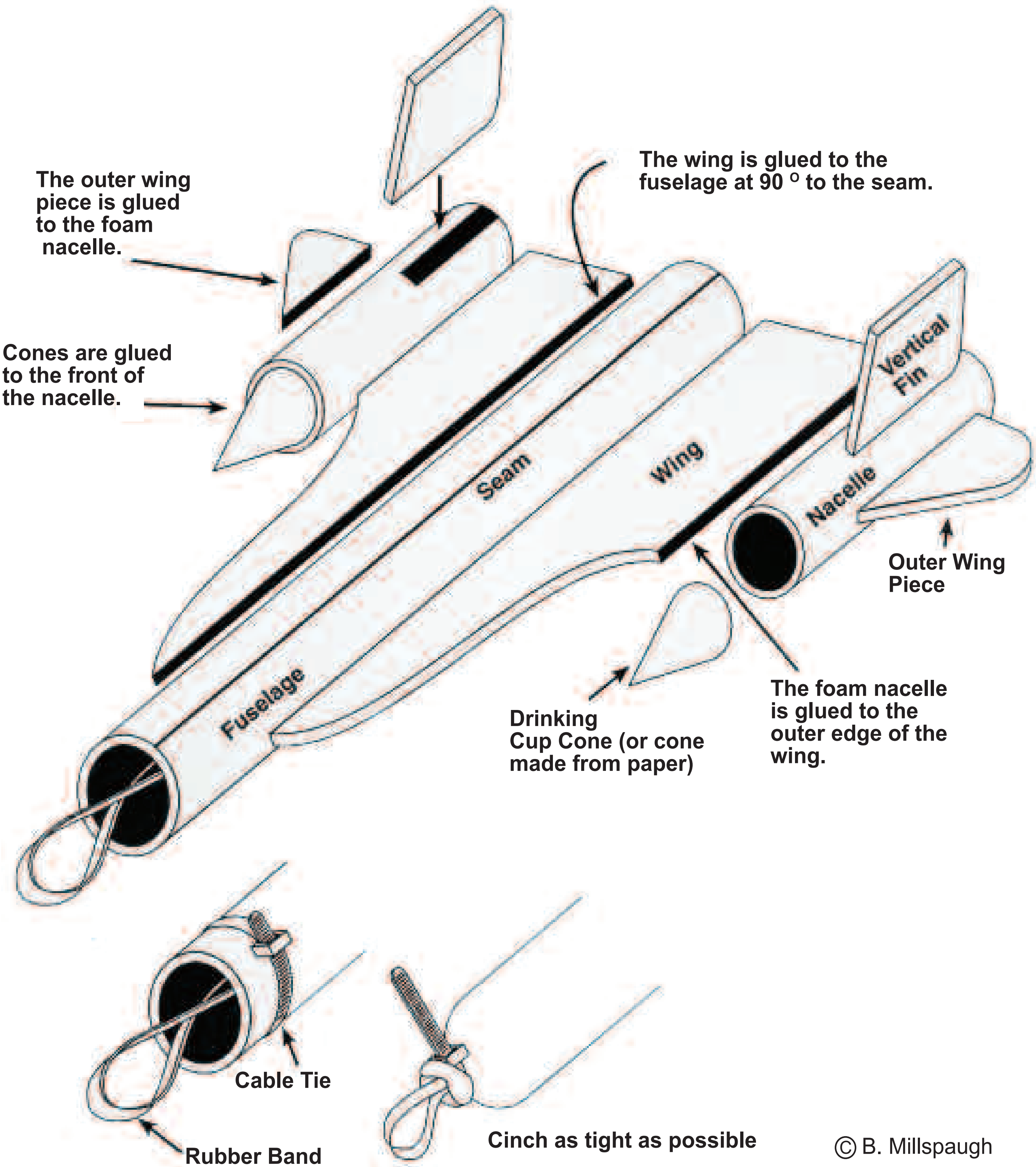
Since 1976, the Blackbird has held the world record for the fastest air-breathing manned aircraft. Thus, it is a unique and noteworthy aircraft to continue to share with young people who it is hoped will take part in the design of future aircraft that can surpass the flying feats of the SR-71. Blackbird.

SR-71 A Blackbird Template

The red dashed lines show where to put the hot glue used to bond the tray foam to the black insulation tubing used to make the fuselage.



SR-71 Blackbird Assembly Diagram



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2 TO FLY BY THE LIFTING POWER OF RISING AIR

Learning Outcomes

- Describe how gliders use the environment to obtain altitude.
- Describe why gliders look different than powered airplanes.
- Discuss how gliders can achieve great distances without power.

EAA Photograph

Important Terms

altitude – the height or distance above a reference plane (The most common planes of reference used in aviation are heights above sea level and ground level. If it's above average sea level, it's referred to "MSL," or Mean Sea Level, and if it's above ground level, it's referred to as "AGL.")
convection – fluid motion between regions of unequal heating
density – mass in a given volume (example: 12 eggs in a basket)
glide ratio – a mathematical relationship between the distance an aircraft will glide forward to the altitude loss (If an aircraft has a glide ratio of twenty to one, and it is one mile above the Earth, it should glide 20 miles before landing.)
lapse rate – the average rate at which temperature decreases with an increase in altitude (The average lapse rate is 3 1/2°F per 1000 feet increase in altitude.)
soaring – the art of staying aloft by exploiting the energy of the atmosphere
stability – the atmosphere's resistance to vertical motion
thermal – a column of air that moves upwards
tow plane – usually a single-engined airplane that will pull a glider from the ground to an altitude where it can be released
wave – a waving action with strong up and down motions started as air moves across mountain ranges (Sailplane pilots can use the motion of this wave to gain altitude.)

RISING AIR CAN MAKE THINGS FLY

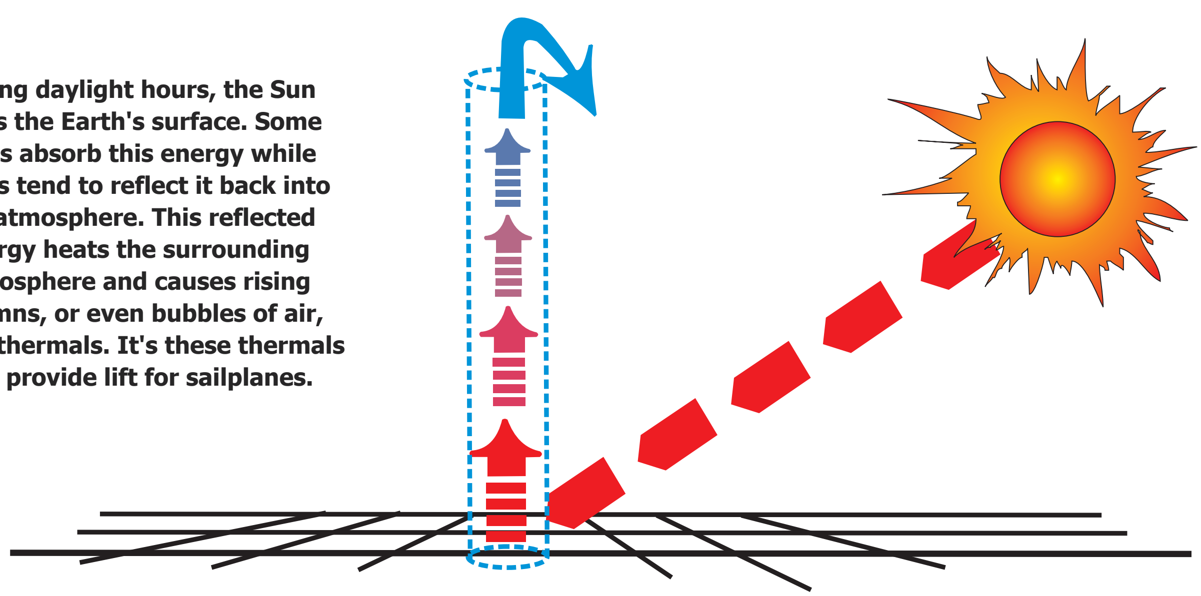
Rising air can have enough energy to provide lift for an aircraft. That's what **soaring** flight is all about. Normally, we think of air moving parallel to the Earth and, of course, we call this "wind." But, there are other factors involved, and one of the most important is the influence that the Sun has upon our environment. From 93,000,000 miles away, the Sun provides energy that causes our atmosphere to move both horizontally and vertically. The vertical motion provides lifting power for sailplanes.

When the surface of the Earth gets warmed by the Sun, the surrounding atmosphere is heated and this causes the air to rise. This vertical motion happens because of a change in the density of the air. As the air becomes less dense, it tends to get lighter and this lighter air wants to rise upward until it cools. This cooling with an increase in altitude is called the **lapse rate**. Normally, the temperature will drop at a rate of 3 1/2° F for every 1000 feet of altitude gained. The Celsius equivalent of this is 2° C per 1000 feet of altitude.

When warm air rises into the colder air at higher altitudes, it cools and then stops rising. After a period of "hanging around," the air begins to sink back toward the Earth. This up and down movement results in a circulation known as **convection**. Sometimes the atmosphere strongly resists this convective circulation and is said to be **stable**.

Two other things happen to air when it is heated; it expands and the pressure drops. Here is an example: In early morning, the air is cool due to low overnight temperatures. The molecules are close together and the atmosphere is more dense when it is cold. When the Sun comes up, it warms the Earth, and this warms the surrounding atmosphere. The molecules start bouncing around at a higher rate due to heat energy. Because they are bouncing around faster and faster, they spread out. This means any given parcel of warm air will be lighter than an equal parcel of cold air. As a result of a decrease in **density** and a lighter weight, the warm air rises. This upward flow has energy in it and given enough power, it can lift a flying machine!

During daylight hours, the Sun heats the Earth's surface. Some areas absorb this energy while others tend to reflect it back into the atmosphere. This reflected energy heats the surrounding atmosphere and causes rising columns, or even bubbles of air, called thermals. It's these thermals that provide lift for sailplanes.



GLIDERS AND SAILPLANES - Aircraft Designed to Ride the Rising Air

When the air moves upward, this **thermal** can provide enough lift and **glide ratio** to keep a competition sailplane up for hours. By technical definition, a glider is an aircraft that is towed to a certain **altitude** and then it glides back to Earth due to the pull of gravity. A sailplane, on the other hand, actually soars on the energy of the environment. The pilot of a sailplane uses every method possible to find lift and then to ride the **wave** to a greater height. (More information about the air environment glider and sailplane pilots use to their advantage for flight is found in Module 3.)

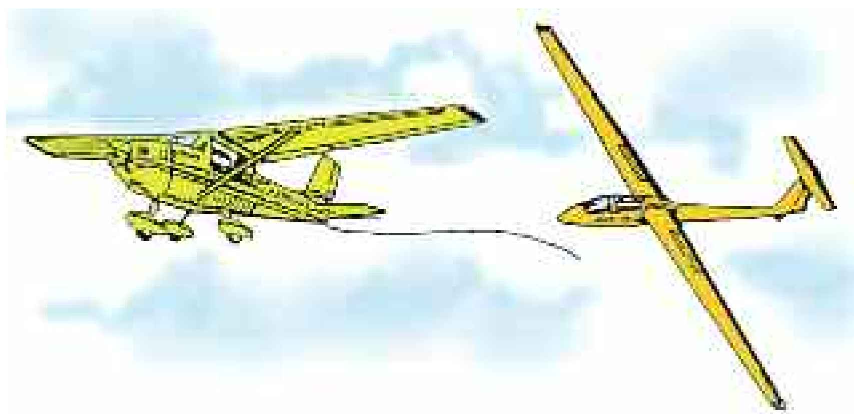
During World War II, the Allies used gliders to haul soldiers into battle. They were towed aloft by transport airplanes and then released over designated drop zones. Once released from the **tow plane**, the skilled glider pilots would try to get the gliders safely back on the ground so the troops could be in a better combat position. In later wars, the glider was replaced by troop-carrying helicopters and this proved far more effective in the combat environment.

The United States Air Force Academy Sailplane

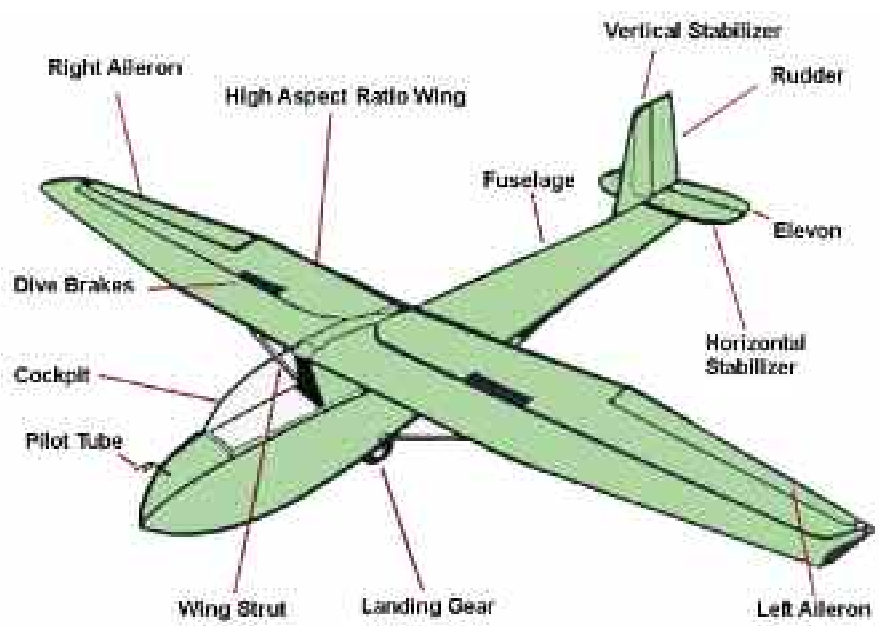
It is the dream of many CAP cadets to someday enter the United States Air Force Academy in Colorado Springs, Colorado. One of the outstanding programs at the Academy is their sailplane training and many cadets get the opportunity to take flight training in a Schweizer TG-4A sailplane.

The sailplane has dual flight controls. The flight control surfaces are actuated by control sticks and rudder pedals through a push rod and cable system. Aileron and elevator control is accomplished through push rods connected to both control sticks. Rudder control is accomplished through cables attached to both sets of rudder pedals.

The USAF Academy TG-4A sailplanes are equipped with instruments which include an airspeed indicator, an altimeter, a vertical velocity indicator, a sensitive variometer, and compass.



After being towed to altitude by a powered aircraft, modern sailplanes are released. The sailplane pilot searches for rising thermals in the atmosphere and these provide lift. (Illustration by Dekker Zimmerman.)



Parts of a sailplane

THE CIVIL AIR PATROL CADET GLIDER PROGRAM

The Civil Air Patrol offers yearly flight encampments on a nationwide basis. These are called "Flight Academies" and provide each participating cadet at least 10 hours of flight instruction with an FAA certificated Flight Instructor. This is called "dual" for one-on-one instruction. Because a cadet is eligible by federal aviation regulation to solo a glider at age 14, this is an outstanding entry-level opportunity for future pilots to acquire important, basic flying skills. Once a cadet has soloed a glider, he/she can then move on to powered flight training at another encampment. The eventual goal is to achieve the coveted Private Pilot's Certificate, which allows a pilot to carry passengers and to fly under visual flight regulations (VFR) virtually anywhere within the Continental United States air space system.

Civil Air Patrol offers all cadets an opportunity to participate in an orientation flight program. This program is designed to give each cadet nine flights during the course of his/her cadet experience. These flights are flown by CAP senior (adult) members who meet specific experience and training requirements as well as through personal background clearance standards. This is by far the best opportunity for a cadet to find out if he/she "really likes flying." It involves "altitude, attitude, and aptitude." (See associated Activity Seven at the end of the chapter.)

Cadets receive a pre-flight briefing on a CAP Blanik L23 glider.

If you find out you "love it," you'll be hooked for life with the "flying bug!"

Thousands of military, commercial, and general aviation pilots had their career start with Civil Air Patrol's glider program. Now it's your turn. If not already a CAP cadet, contact www.capmembers.com to find out how you and your friends can join!

ACTIVITY SECTION 2

Activity Seven -
Zia Glider

Purpose: Build a Zia glider and observe how a glider flies.

Materials: cardstock, hobby knife, ruler, glue, paper clips, a little clay, and glider pattern (cutouts) on the following page (use this one or a color copy of it)

Procedures:

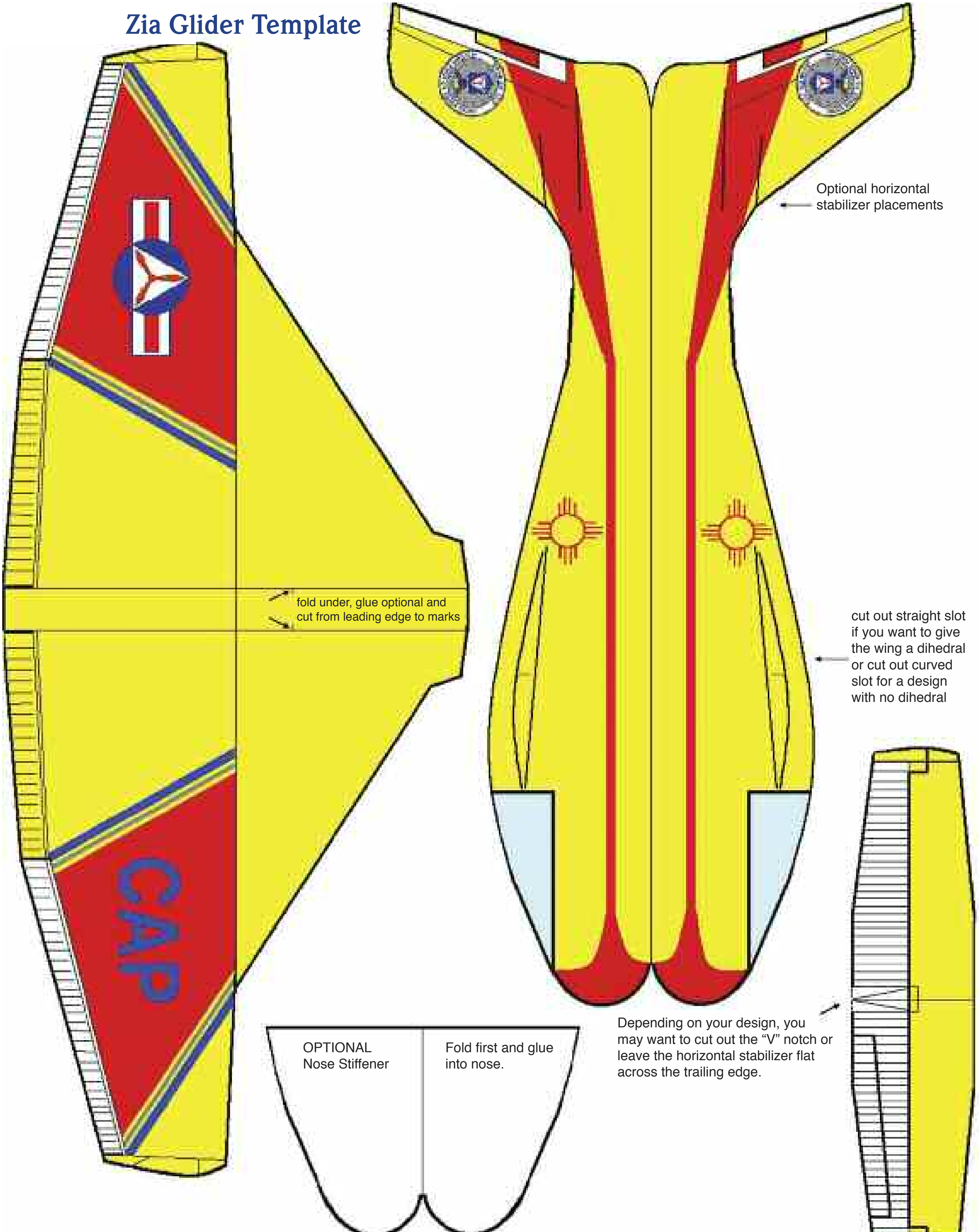
1. Glue the entire pattern page to the piece of cardstock (a file folder is excellent for this project).
2. Cut out the designs from the attachments.
3. Use ruler to help fold movable parts.
4. Glue the pieces together to build the glider.
5. Fly your glider, experimenting with different positions of the control (movable) parts.
6. Add a small piece of clay to the nose area (experimenting to get the accurate amount) for "stabilization" (better control stability of flight).

Notes: The following recommendations make building a cardstock glider much more successful.

- It is recommended that a hobby knife be used to cut out cardstock models. Scissors are acceptable, but a knife, like the X-Acto® #11, can make more precise cuts. (adult supervision suggested.)
- Use a ruler to score long bends, like the point where the fuselage of the ZIA is folded.
- A high quality white or carpenter's glue, or spray glue, works well on these models. Be patient, paper glue takes longer to dry.
- Super glue also works, but there's always the problem of getting your fingers glued together. Have an adult help when working with super glues.
- All gliders, whether they are cardstock or balsa, usually require a little nose weight to make them fly. Use the clay for this step, trying different amounts until your glider flies as desired.

Summary: In this activity, cardstock is used to copy a pattern of the Zia Glider and techniques are taught to put together a quality model and to learn to fly it effectively as a glider. The Zia Glider is a high-wing design with no dihedral (the upward angle of a fixed-wing aircraft's wings) and tends to go unstable if the trim (the cuts and folds for movable parts) is not set exactly. One possible class exercise might include how dihedral works to make aircraft stable and then problem solve how the airplane design could be modified to improve stability.

Zia Glider Template



designed by William H. Jackson, Capt, CAP

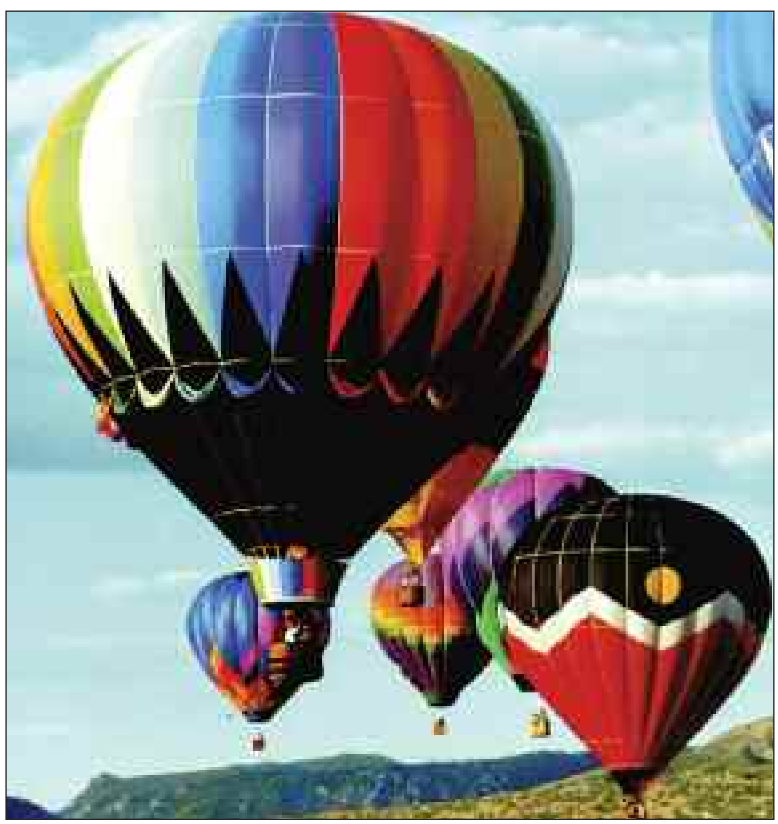
3 BALLOONS – THEY CREATE THEIR OWN THERMALS

Learning Outcomes

- Define the principle of buoyancy and how this relates to the flight of a balloon.
- Describe the components of a balloon and how each works in the flight profile.
- Describe the history of the balloon and why it's recognized as the first powered, manned flight.

Important Terms

altimeter – instrument to provide the height of the balloon above sea level
balloon – an aircraft that uses lighter-than-air gas for its lift, with no built-in means of horizontal control
burner – the heat source for filling the envelope with hot air
buoyancy – to rise or float on the surface of water or within the atmosphere
crown – the top of the hot air balloon's envelope
envelope – the main body of the balloon, usually made of nylon, that is filled with lighter-than-air gas
gondola – a wicker basket, hanging below the envelope, used to transport passengers and propane tanks
gore – one of several vertical panels that make up the envelope
Montgolfier – the name of the two French brothers who created the first successful, manned, hot air balloon in 1783
parachute panel – located in the top of the balloon's envelope that allows it to be deflated (When a larger area of deflation is needed, some balloons are equipped with a rip panel.)
propane – a lightweight, low carbon fuel used in hot air balloon burners
thermistor – an instrument which measures the temperature within the envelope
variometer – an instrument to determine the rate of climb or descent; sometimes referred to as vertical velocity indicator



BALLOONS WERE FIRST

Two brothers, Joseph and Etienne **Montgolfier**, were well-educated Frenchmen who enjoyed researching science and flight. In 1782, after having read scientific papers about the properties of air, they noticed sparks and flames rising in their fireplace. So, they took a small bag of silk, lit a fire underneath it, and watched it rise. They soon began experimenting outdoors with larger bags made of paper and linen.

In 1783, their earlier experiments led to a demonstration with a **balloon**. Then, in September 1783, in a demonstration before King Louis XVI and Marie Antoinette, they attached to a balloon a cage with a sheep, a roster, and a duck inside. All of the "passengers" were carried aloft and landed safely.

Then on November 21,1783, the first successful manned, powered flight was made in a Montgolfier balloon. Two Frenchmen, Pilatre d'Rozier and the Marquis Francois d'Arlandes, flew their way into history aboard a balloon launched in Paris. The flight lasted about 25 minutes and it landed approximately five miles from the launch point. The race toward the skies had begun! (Note: The Wright Brothers are credited with the first manned, controlled, powered flight. Since hot air balloons can not be completely controlled, due to the unpredictability of the wind, the Wright Brothers' status was achieved when the brothers made their historic flight December 17, 1903.)

How They Fly

A balloon operates on the principle of **buoyancy**. It all happens because hot air is lighter, or more buoyant, than cold air. Imagine that you have two parcels of air the same size. If the air in one parcel is hot and the other is cold, the warm-air parcel will be lighter. If you could insert the hot parcel of air inside a very lightweight balloon, it would rise into the surrounding colder air. With enough hot air, a balloon will lift not only itself, but passengers, instruments, fuel, and all of the equipment needed for a flight. The large container that holds this hot air is called the **envelope**. There are strips of very strong material along the vertical length of a balloon that attach the envelope to the basket. These are known as load tapes. These are also horizontal load tapes, as shown on page 40.

A replica of the Montgolfier balloon is on display in the US National Air and Space Museum.

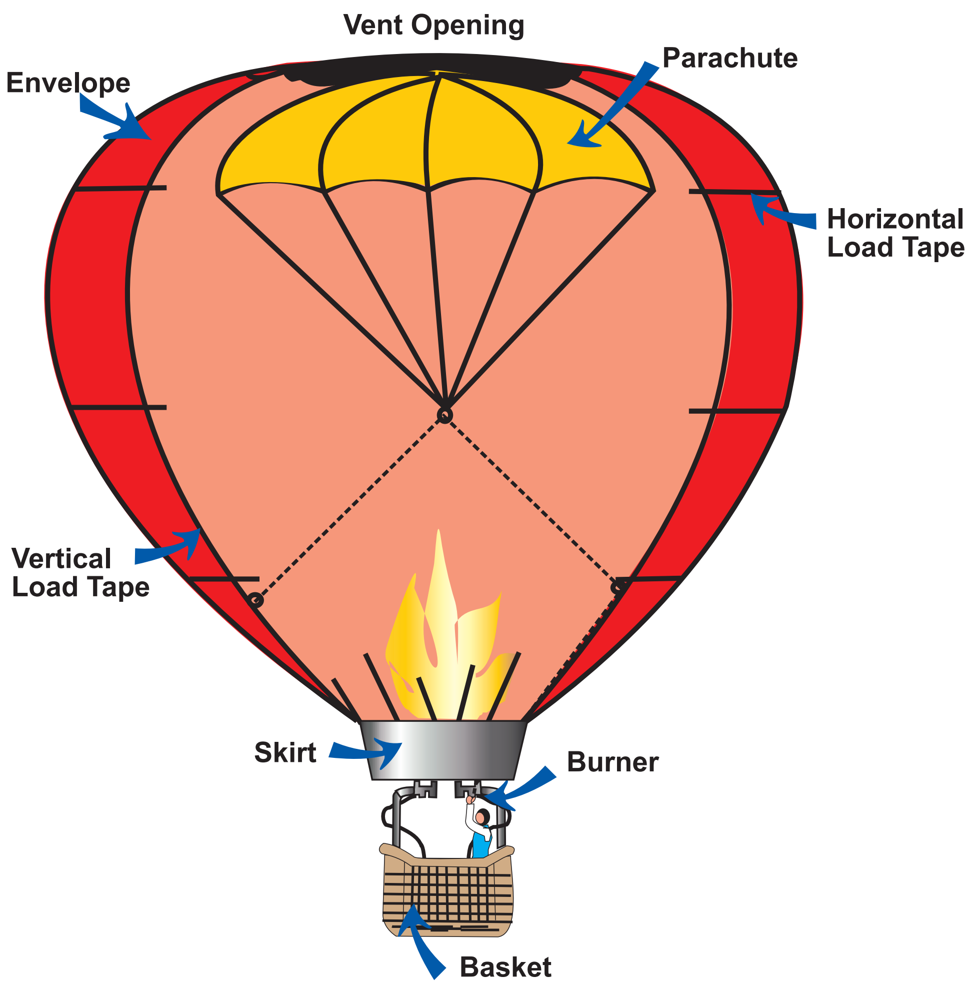
Power for the balloon is provided by a propane **burner** that quickly heats the air inside the envelope. The **propane**, in liquid form, is stored in tanks carried in the basket, called the **gondola**. When the pilot pulls a cord, the liquid propane rushes through a series of vaporizing coils and is ignited by a pilot flame at a jet in the burner. During ascent, it is quite common to have temperatures inside the envelope reach 212° Fahrenheit. To get this kind of heat, burners need to produce several million BTU's/ hour. For clarification, A BTU is a "British Thermal Unit" and by definition it is a measure of heat. It is defined as the amount of heat required to raise the temperature of one pound of water, one degree Fahrenheit. The metric equivalent of the BTU is a Calorie. A Calorie is the amount of heat required to raise the temperature of one Kilogram of water, one degree Celsius.

A balloon floats on the wind and directional control is minimal. At various altitudes, wind direction can change and pilots take advantage of this by climbing or descending to get the balloon to change direction.

The Mathematics Of A Balloon's Lifting Power

In the excellent book, *Ballooning, A Complete Guide To Riding The Winds,* by Dick Wirth and Jerry Young, an explanation is given for the lifting power of a balloon. *"Typically, a (hydrogen) gas balloon will derive about 60 lbs. of lift per 1,000 cu. ft., whereas a hot-air model will develop only 17-20 lb. per 1,000 cu. ft. (at 100-120 degrees Celsius). Thus, a 77,000 cu. ft. balloon will lift: 77 x 17 = 1,309 lbs. gross lift."*

The authors state that the envelope will weigh about 160 lbs., the burner and basket will weigh collectively 150 lbs., and four gas tanks will weigh 290 lbs. This gives a total aircraft weight of 600 pounds. If the balloon has a gross lifting power of 1,309 pounds, that means it will carry 709 pounds under standard conditions. Divide 709 by the weight of an average human at 170 pounds and the balloon will carry 4.17 persons, or three passengers, one pilot, and some miscellaneous equipment.



To ascend, or go up, the pilot lights the burner to create hot air inside the envelope. To descend, or go down, the pilot can pull down on the parachute control and this allows hot air to escape out the vent opening at the top of the envelope, called the crown.

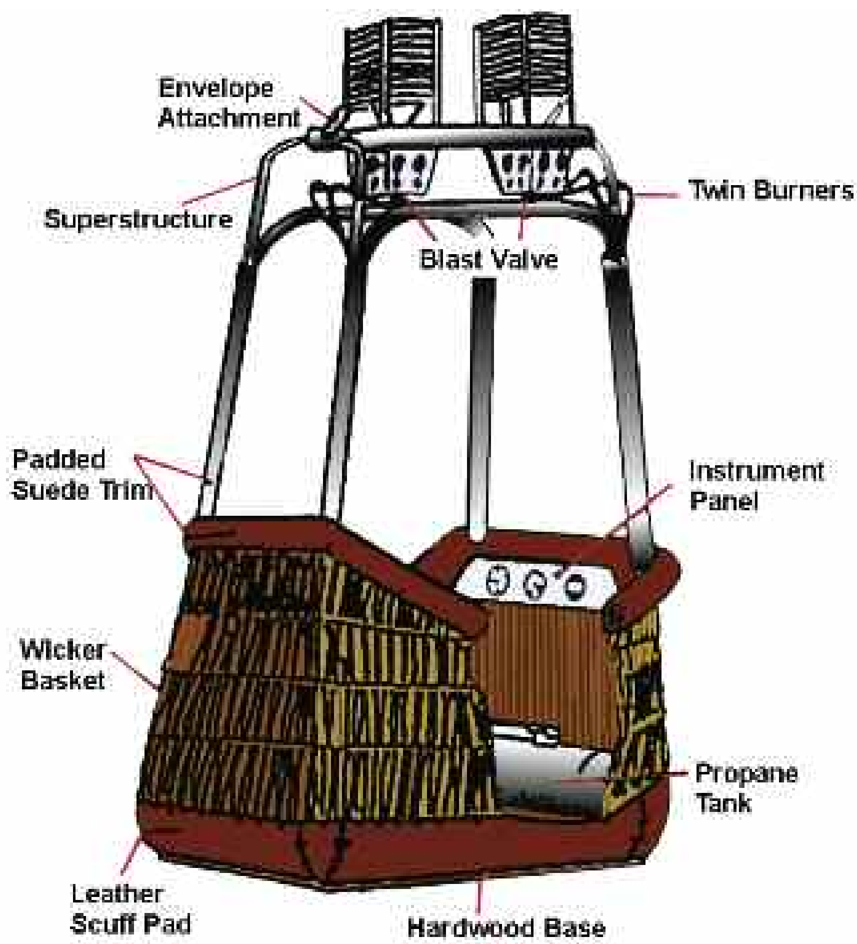
Construction Of A Balloon's Envelope

A large volume of lightweight air is best contained in a sphere. If you study a hot air balloon closely, as shown on page 40, you will notice that the general shape of the envelope is spherical. To make the shape of a balloon, a series of panels are sewn together. These panels are called **gores**. The fabric most widely used is nylon and dacron, a form of polyester. There are advantages to both of these fabrics. Dacron will withstand higher temperatures, but nylon is lighter and stronger. The fabrics are coated with polyurethane and other additives to give it longer wear and greater resistance to ultraviolet sunlight damage. Most fabrics weigh between 1.2 and 2.4 ounces per square yard.

The Basket – A Balloon Pilot's Cockpit

The basket of a balloon is its cockpit. The fuel for the burners is liquid propane and is carried along in cylindrical tanks. When the liquid propane passes through the coils on top of the burner, it vaporizes. A small pilot flame ignites the propane and a much larger flame shoots up through the skirt into the envelope.

A balloon pilot's control system is the ascent and descent power of the burner. There is a panel inside of a hot air balloon that allows some of the hot air to escape. It's called the **parachute panel** and looks somewhat like a conventional parachute only it fills a hole in the top of the balloon, called the **crown**. This hole is known as a vent. The vent varies from 6-18 feet across. The parachute is held in place by cords inside the envelope. The hot air pressure inside the balloon keeps the parachute in place; however, when the pilot wants to release some of the hot air, a cord is pulled which draws the parachute downward thus opening the vent hole. When the cord is released, the parachute is pushed back into the vent, closing it so the rest of the hot air is not allowed to escape.



Cockpit Instrumentation

Generally, the pilot has only three instruments on the instrument panel. One of the most important is the vertical velocity indicator, or **variometer**. This gives the pilot an indication of the rate of climb and descent. Next, the pilot has an instrument that gives a measurement of the temperature at the top of the balloon and it is known as a **thermistor**. This is an electronic warning instrument that shows the pilot when the temperature is dropping and a descent is about to occur. The optimum temperature inside the crown is around 100 degrees Celsius. Finally, an **altimeter** is installed that provides the height of the balloon above sea level.

Flying in a Hot Air Balloon

If you ever have the opportunity to fly in a hot air balloon, do it! This flight is one of the most peaceful and beautiful flights you'll ever experience. Being so close to the balloon pilot and the control equipment will enable you to get a very good idea of how the balloon actually flies. Observing the pilot's continued attention to both ground and aerial structures, to the need for greater or lesser altitude, and to the safety in using the propane tanks will place you directly in the ongoing action of balloon flight. It is a wondrous thing to behold. (See associated Activity Eight at the end of the chapter.)

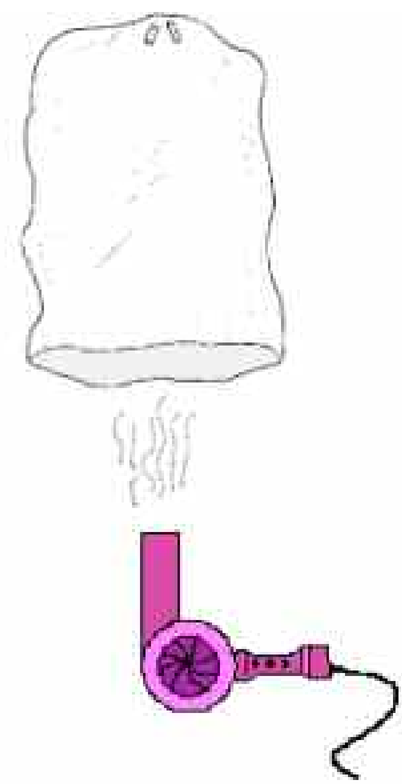
Balloons have priority over all other aircraft in flight when flight plans have been submitted. If you look under the balloon, you'll see the crew in a tiny basket. They're doing what pilots do best—having fun!

3 ACTIVITY SECTION

Activity Eight -
Hot Air Balloon

Purpose: Construct a model hot air balloon and help reinforce the understanding of how a hot air balloon works.

Materials:
- dry cleaner plastic film bags or very thin garbage bag liners (Select the type of bag with the thinnest possible plastic and have several on hand. You may have to experiment with bags of different thicknesses.)
- several small paper clips
- cellophane tape
- blow dryer (with hot temperature setting)



Safety: If the bag starts to crumple and melt from the heat, set the blow dryer on a lower setting or hold the bag farther from the heat source.

Procedures:
1. Seal any openings and tears in the upper end of the bag with a minimum of cellophane tape.
2. Turn on the blow dryer (or other hot air source). Spread the bag opening wide to capture the rising hot air while supporting the upper end with your hand. It is best to have assistance in keeping the bag open so that it does not melt.
3. When the bag is inflated with hot air, test its buoyancy by letting it go for a moment. If it rises quickly, stand back and let it lift. Otherwise, continue heating it for a little while longer.
4. Attach several paper clips to the plastic around the lower opening. Have students experiment with the number of paper clips that are needed to keep the balloon from rising too high, but that are needed for the balloon to stay afloat.
5. Release the balloon for its flight. If the bag tips over and spills its hot air before it reaches the ceiling, add a few more paper clips to slightly weigh down the bottom. If the bag will not rise at all, remove a few clips.

Summary:

Hot air is less dense than cold air. Heat accelerates the motion of the air molecules causing fewer molecules to occupy the same space as a much greater number of molecules do at a lower (cooler) temperature. With fewer molecules, the hot air has less mass, weighs less, and, therefore, is buoyant.

Placing the dry cleaner bag over the heat source captures the hot air and forces out the cooler air in the bag. The bag becomes a mass of low-density air which floats upward in the cooler denser air surrounding it. The paper clips are placed at the bottom of the bag to keep the open end downward in flight to prevent it from prematurely spilling the hot air and terminating the flight.

As this chapter closes with this last activity, your group may want to build or purchase a larger tissue paper balloon to have an outdoor launch. For information about purchasing a hot air balloon, go to Edmund Scientific at http://scientificsonline.com or Pitsco at http://catalog.pitsco.com.
For information about building and launching a hot air balloon, go to the CAP AE website at www.capmembers.com/ae. Click on the *lessons and other resources* box to find the *hot air balloon* section which includes full directions for building a tissue paper hot air balloon.